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Document Modification Request

25 DMR No 96-DMR-RMRS-0117

Originator

Print or Type all information (except signatures) Process procedures in accordance with 1 A01-PROC DEV-400 Procedure Process.

1 Name/Phone/Pager/Location: Annette Primrose

2 Date: 11/13/96

3 Existing Document Number and Revision: GT 1 ~~Log~~ Rev 2

4 Document Type: [X] Procedure [ ] Plan [ ] Other

5 Document Title: Logging Alluvial & Bedrock material

	6 Item	7 Page	8 Step	9 Proposed Modification
1	G	ALL		Delete references to E6¢6
2	M	4	2.0	Add to end of ~~3rd~~ 2nd paragraph "This procedure does not apply to alluvial or bedrock materials derived from geoprobe investigations"

10 Item	10a Justification (reason for modification, EJO #, TP #, etc.)
2	Insufficient material is collected during geoprobe operations to comply with this procedure.

Originator's Supervisor MARLA BROUSSARD M Broussard 11-14-96 (print/sign/date)

11 [X] Process
[ ] Do not Process (state reason in Block 10a)

12 [X] Process (Complete Blocks 13-22) (print/sign/date)
[ ] Do not Process (state reason in Block 10a)

13 New Document/ Rev No. (if new or changed): N/A

Complete either Section 14a or 14b as applicable. For procedures, attach completed Procedure Modification Worksheet from 1-A01-PROC DEV-400

14a. Type of Complete Modification: [ ] New [ ] Revision [ ] One-Time-Use [ ] Cancellation

14b Changes (check all that apply): [X] Intent Change [ ] Editorial Correction [ ] Nonintent Change [ ] Regular [ ] Interim Approval Requested Needed for Immediate Use (14-day limit for obtaining final approval)

Additional Attributes: [ ] Temporary [ ] One Time-Use [ ] Limited Distribution

15 ERM Change Control Board Required: [ ] Yes [X] No (Applicable only to new procedures, revisions and intent changes.)

List the reviewing disciplines in Block 16. After concurrence has been obtained (in accordance with 1 A01-PROC DEV-400), enter the name of the reviewer followed by /s/ in block 17 If the reviewer indicates *No comments*, the review signature constitutes concurrence Enter the date concurrence is obtained in Block 18

16 Organization	17 Reviewer/Concurror	18 Date	16a. Organization	17a. Reviewer/Concurror	18a. Date
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ADMIN RECORD

A W 00 351

LOGGING ALLUVIAL AND BEDROCK MATERIAL

Rocky Flats Environmental Technology Site		
~~EG&G ROCKY FLATS PLANT~~	**Manual:**	**5-21000-OPS**
EMD MANUAL OPERATION SOP	**Procedure No.:**	**GT.1, Rev 2**
	Page:	**1 of 34**
	Effective Date:	**March 1, 1992**
Category 2	**Organization:**	**Environmental Management**

TITLE
LOGGING ALLUVIAL AND BEDROCK MATERIAL

Approved By:
(Name of Approver) 5/12/92 (Date)

1.0 TABLE OF CONTENTS

(4011-930-0062-930)(GT1REV.2)(03/02/92)

REVIEWED FOR CLASSIFICATION/UCNI
By
Date March 9, 1992

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2.0 PURPOSE AND SCOPE

Over the period of the last few years, it has become apparent that a standardized procedure is needed for logging alluvial and bedrock material This need has arisen because each subcontractor has slightly different procedures and criteria for logging borehole material Beginning in 1991, all subcontractors will use the procedures that are covered in this SOP

By applying these techniques and procedures, it will be possible to standardize the logging of alluvial and bedrock materials In addition, the number of errors and the amount of relogging will be reduced This will allow lithologic descriptions to be compared from year to year and will enable the environmental management staff on the Rocky Flats ~~Plant (RFP)~~ Environmental Technology Site site to make interpretations based on reliable data This procedure does not apply to RFETS alluvial or bedrock materials derived from geoprobe investigations.

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On the ~~RFP~~ RFETS site, "alluvial material" includes alluvium, colluvium, fill, and agronomic soils Samples of alluvium, colluvium, fill, and agronomic soils are to be classified and described using the Unified Soil Classification System (U S C S) and enhanced by Item 10 1 in ASTM D2488, "Description and Identification of Soils (Visual-Manual Procedure) " Bedrock material, regardless of the degree of weathering, is to be classified and described by using many of the procedures and techniques described in Compton's "Manual of Field Geology" (1962), which has been incorporated with additional material in this SOP

3.0 RESPONSIBILITIES AND QUALIFICATIONS

The ~~EG&G~~ ER Project Team project manager has the overall responsibility for implementing this SOP The subcontractor's project manager will be responsible for assigning project staff to implement this SOP and for ensuring that the procedures are followed by all subcontractor personnel

All personnel performing these procedures are required to have the appropriate health and safety training as specified in the site-specific Health & Safety Plan In addition, all personnel are required to have a complete understanding of the procedures described within this SOP and receive specific training regarding these procedures

Only qualified personnel will be allowed to perform these procedures Required qualifications vary depending on the activity to be performed In general, qualifications are based on education, previous experience, on-the-job training, and supervision by qualified personnel Personnel who log alluvial boreholes must study the ~~RFP~~ RFETS Alluvial Reference Set that contains examples of all 15 sample classifications within the U S C S System Personnel who log bedrock boreholes must be qualified geologists or geologic engineers, who have received special permission to log bedrock holes All of the loggers must study the Core Reference Set that contains 15 representative samples of the stratigraphic section in the ~~RFP~~ RFETS area In addition, they must study the Alluvial Reference Set These reference sets are used as training guides to help ensure consistency among logging geologists The subcontractor's project manager will document personnel qualifications related to this procedure in the subcontractor's project Quality Assurance (QA) files

96-DMR-RHRS-0117

All project staff are responsible for reporting deviations from this SOP to the individual's project manager The subcontractor's project manager will report deviations and nonconformances to the ~~EG&G~~ project manager ER Project Team

When field conditions require deviations from the SOP, a Document Change Notice (DCN) will be authorized by an ~~EG&G~~ ER Project Team EMD logging supervisor An ~~EG&G~~ ER Project Team EM Department Administrative Procedure outlines the DCN approval process

4.0 REFERENCES

4.1 SOURCE REFERENCES

The following is a list of references reviewed prior to the writing of this procedure

ASTM Method for Particle - Size Analysis of Soils, Soil and Rock Dimensions, Stone and Geo-Synthetics Vol 04 08 Sec D422 1989

ASTM Practice for Description and Identification of Soils for Engineering Purposes (Visual-Manual Procedures), Soil and Rock Dimensions, Stone and Geo-Synthetics Vol 04 08 Sec D2488 1989

Blatt, H , Middleton, G , Murray, R Origin of Sedimentary Rocks Prentice-Hall 1972

Compton, Robert R Manual of Field Geology John Wiley & Sons, Inc 1962

Harlan, R L , Kolm, K.E , Gutentag, E D Water-Well Design and Construction Development in Geotechnical Engineering, #60 Elsevier 1989

Krumbein, W C , Pettijohn, F.J Manual of Sedimentary Petrography Appleton-Century-Crofts 1966

Unified Soil Classification System Appendix A. Characteristics of Soil Groups Pertaining to Embankments and Foundations, Appendix B. Characteristics of Soil Groups Pertaining to Roads and Airfields (U S) Army Engineer Waterways Experiment Station Vicksburg, MS 1960

5.0 CLASSIFICATION/DESCRIPTION

5.1 UNIFIED SOIL CLASSIFICATION SYSTEM (U.S.C.S)

The U S C S classification system will be used at ~~RFP~~ RFETS The U S C S , as used in this SOP, has been modified from the Army Corps of Engineers' Technical Memorandum No 3-357, "The Unified Soil Classification System" (1960) Physical characteristics, which are normally determined through laboratory analyses, are not included in this SOP because they are neither practical to do in the field nor appropriate to geologic logging A reprint of the U S C S is enclosed in Appendix GT 1A

5.1.1 Basis of Classification

The U S C S historically has been used to classify "soils" based on their textural properties, liquid limit, and organic content In the past, the term "soil" has been used by engineers as a catchall term that includes all unconsolidated material Because engineers are concerned with how the soil behaves as a construction material, this all-inclusive approach has served them quite well

However, in this SOP, the U S C S will be applied only to alluvium, colluvium, fill, and agronomic soils This has been done to separate unconsolidated cover material from bedrock that has well-defined sedimentologic and depositional patterns, regardless of the degree to which the bedrock has been weathered In the ~~RFP~~ RFETS area, it is more important to determine the possible paths of groundwater movement based on lithologic variability and geologic processes than it is to determine the engineering properties of weathered bedrock based on its physical behavior

5.1.2 Texture

5.1.2.1 Grain Size Scale

The U S C S grain size scale is divided into four main categories (1) cobbles, (2) gravel, (3) sand, and (4) fines The gravel, sand, and fines are subdivided into coarse and fine gravel, coarse, medium, and fine sand, and silt and clay

Table GT.1-1 is a summary of the U S C S grain size scale as well as the Wentworth, Atterberg, and U S Department of Agriculture grain size scales (Krumbein and Pettijohn 1966, and Compton 1962) In this SOP, the U S C S grain size scale is used when logging alluvium, colluvium, fill, and agronomic soils, whereas the Wentworth scale is used for logging bedrock

Neither the U S C S nor the U S Department of Agriculture grain size scales have a common base However, both the Wentworth and the Atterberg grain size scales are geometric series with a base of 2 and 10, respectively

It should be noted that the divisions between gravel and sand, as well as those between sand and silt, vary from scale to scale This makes it somewhat difficult to compare the U S C S grain size analyses with analyses based on other scales Most geotechnical laboratories show only the U S C S grain size ranges on the graph paper Figure GT 1-1 is a modified graph that shows both the U S C S and Wentworth grain size ranges ASTM D422, "Particle-Size Analysis of Soils," should be used to perform the grain size analyses but should be modified to include a 230 sieve when bedrock is being analyzed

Sieves and grain size charts should be used regularly when grain size determinations are made It is important to mention that a small degree of error is inherent between grain size determinations made in the field and those derived in the laboratory Field analyses are based on volumetric (visual) measurements, whereas the laboratory analyses are based on weight measurements However, the procedures employed in this SOP significantly reduce the margin of error

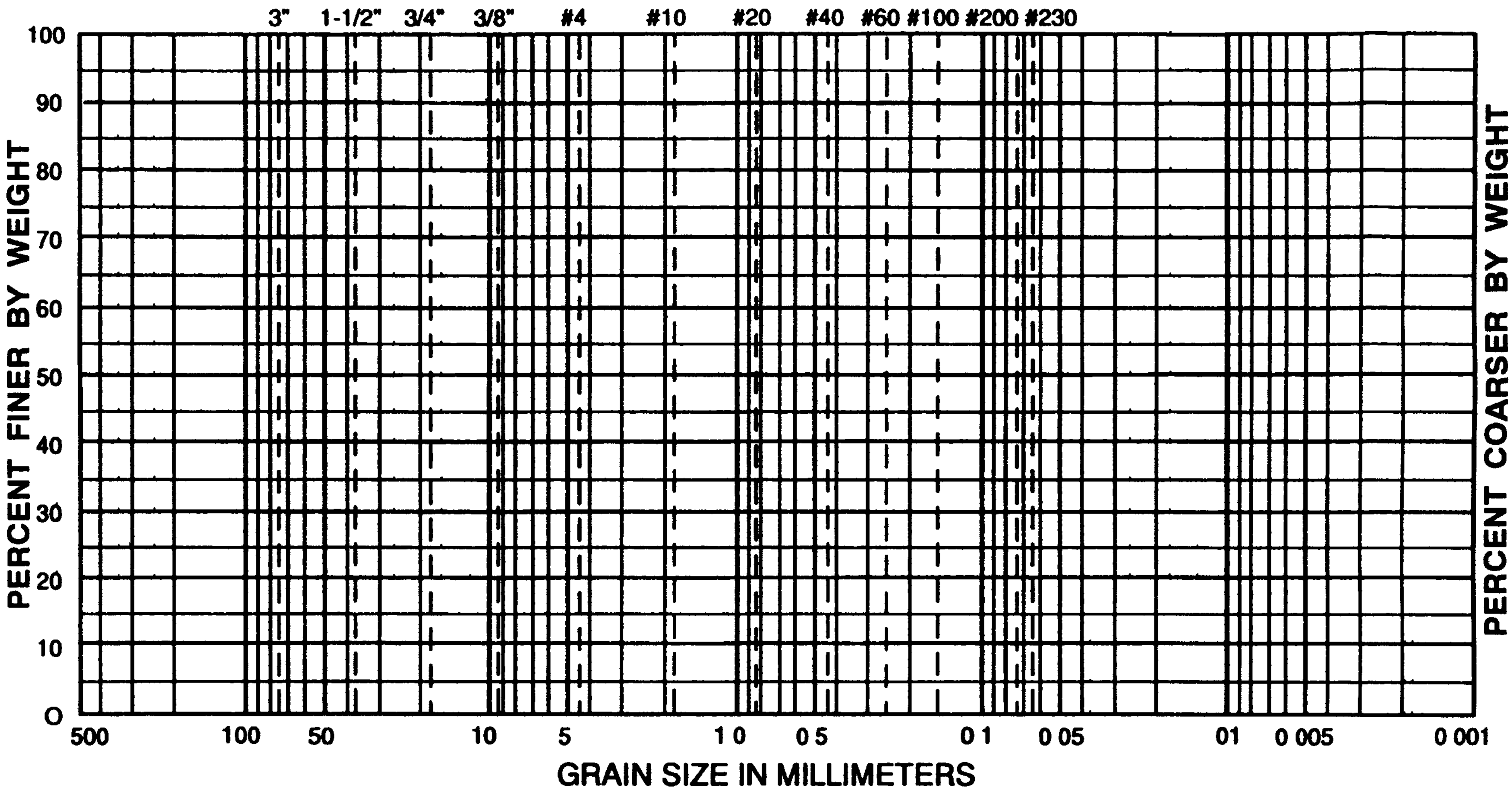
The logger is responsible for subdividing the core into intervals of similar lithologies From each interval, a small representative sample will be collected, dried, desegregated, and sieved, using the appropriate sieve nest The volume of material in each size class will be measured using graduated cylinders and beakers and recorded The logger must record the percentages of gravel, sand, silt, and clay Percentages of silt and clay can be estimated with the aid of a binocular microscope The percentage of abundance diagrams in Figure GT 1-5 and the soil reference set will be used when appropriate All percentages should normalize to 100% and be recorded in the grain size column of the logging form

TABLE GT 1-1

Grain Size Scales (millimeter[mm])

U S C S	Wentworth	Atterberg	U S Dept Ag.	Component
>76 2	256-64	200-20	>80	Cobbles
--	64-32*	--	--	V C. Gravel
76 2-19	32-16*	--	--	C. Gravel
--	16-8*	20-2*	80-2	M Gravel
19-4 76	8-4*	--	--	F Gravel
--	4-2	--	--	Granule
--	2-1	--	2-1	V C. Sand
4 76-2	1-0.5	2-0 2	1-0.5	C. Sand
2- 42	0.5-0.25	--	0.5-0 25	M Sand
42- 074	0 25-0 125	0 2-0 02	0 25-0 1	F Sand
--	0 125-0 0625	--	0 1-0 05	V F Sand
< 074	0 0625-0 0039	0 02-0 002	0 05-0 002	Silt
--	<0 0039	<0 002	< 002	Clay
Variable	Base 2	Base 10	Variable	
*Pebbles				

U.S. STANDARD SIEVE SIZE
FIGURE GT.1-1



USCS	COBBLES	GRAVEL		SAND			SILT OR CLAY
		COARSE	FINE	COARSE	MEDIUM	FINE	

WENTWORTH	COBBLES TO BOULDERS	PEBBLE GRAVEL				SAND			SILT	CLAY
		COARSE	MED	FINE	GRAN	COARSE	MED	FINE		

WELLNAME ____________ SAMPLE NO ____________ DATE: ____________ PROJECT NO ____________

AREA	DEPTH	CLASSIFICATION

5.1.2.2 Graded Material

The concept of graded material is used to describe the number of grain size ranges that are present within the central portion (approximately 80 percent) of the grain size distribution for samples with less than 5 percent fines (silt and clay) If 80 percent of the sample contains predominantly one or two grain size ranges (such as medium and fine sand), it is poorly graded and has a symbol (P) If 80 percent of the sample contains three or more grain size ranges (such as fine gravel, coarse sand, medium sand, and fine sand), it is well graded and has a symbol (W)

Field values may be checked after the grain size analyses have been calculated and plotted The uniformity coefficient is a useful value that may help determine whether a gravel or a sand is well graded The formula for the uniformity coefficient is

$$U_c = D_{60}/D_{10}$$

where the D values are read directly from the grain size plots and represent the amount of material that is finer by weight Well-graded gravels have a value greater than 4, and well-graded sands have a value greater than 6

5.1.3 Field Estimates of Plasticity

The plasticity characteristics of fine-grained alluvium or the fine fraction of a coarse alluvium should be determined per the procedures covered in the U S C S (Appendix GT 1A) The following paragraph and paragraph excerpts are taken from the U S C S in Appendix GT 1A

"Particles larger than about the No 40 sieve size are removed (by hand), and a specimen of soil about the size of a 1/2-inch cube is molded to the consistency of putty If the soil is too dry, water must be added, and if it is sticky, the specimen should be spread out in a thin layer and allowed to lose some moisture by evaporation The sample is rolled by hand on a smooth surface or between the palms into a thread about 1/8 inches in diameter The thread is then folded and rerolled repeatedly During this manipulation, the moisture content is gradually reduced and the specimen stiffens, finally loses its plasticity, and crumbles when the plastic limit is reached After the thread crumbles, the pieces should be lumped together and a slight kneading action continued until the lump crumbles The higher the position of the soil above the 'A' line on the plasticity chart the stiffer are the threads as their water content approaches the plastic limit and the tougher are the lumps as the soil is remolded after rolling"

5.1.3 1 Low Plasticity

Alluvial samples with a low plasticity "form a weak thread and cannot be lumped together into a coherent mass below the plastic limit"

5.1.3.2 Medium Plasticity

Alluvial samples with a medium plasticity "form a medium tough thread (easy to roll) as the plastic limit is approached but when the threads are formed into a lump and kneaded below the plastic limit, the soil crumbles readily"

5.1.3.3 High Plasticity

Alluvial samples with a high plasticity form a stiff thread "as their water content approaches the plastic limit and the tougher are the lumps as the soil is remolded after rolling."

5.1.4 **U.S.C.S. Sample Classification**

The sample classifications of the U S C S are illustrated in Figure GT 1-2 In order to classify alluvium, colluvium, fill, and agronomic soils, it is necessary first to estimate the percent of all the grain size ranges in the sample and determine the plasticity of the fines if they comprise more than

50 percent of the sample With this information, enter Figure GT 1-2 from the left and progress to the right matching the textural, plasticity, and organic characteristics of the sample

The progression through Figure GT 1-2 is an "if/then" sequence of decisions that ultimately leads to the proper sample classification For borderline gravel and sand soil classifications whose fines content ranges from 5 to 12 percent, a split classification should be assigned based on the two dominant soil types with the main type given first A split classification is also justified for gravel and sand soil types having equivalent percentages of coarse fraction material passing the no 4 sieve Log descriptions should identify the appropriate U S C S symbol(s) and associated lithologic (graphic) log, however, the sample description should reflect the most frequent grain size in a manner consistent with the classification for bedrock units (see Section 5 2.5) Two examples follow

- Example 1 Seventy-five percent of the material is greater than the No 200 sieve, 53 percent greater than the No 4 sieve (gravel), 22 percent is sand, and 25 percent is fines (10 percent silt and 15 percent clay) The proper classification for this sample is a sandy gravel with some clay and silt (GC)

- Example 2 Eighty-five percent of the material is smaller than the No 200 sieve, 5 percent is gravel; 10 percent is sand, 30 percent is silt; and 55 percent is clay that has a low to medium plasticity The proper classification for this sample is a silty clay with some sand and a trace of gravel (CL)

Note Both examples use the range of abundance terms defined in Section 5 2 3 1

Generally, sample descriptions should be made in the following order

- Main textural classification with modifiers

FIGURE GT.1-2 SOIL TYPES

Major Divisions			Letter	Symbol	Description
Coarse Grained Soils More than 50% of material is larger than no 200 sieve size	Gravel and Gravely Soils More than 50% of coarse fraction retained on no 4 sieve	Clean Gravels (< 5% fines)	GW		Well graded gravels or gravel-sand mixtures, little or no fines. Uc > 4 (lab only)
			GP		Poorly graded gravels or gravel-sand mixtures, little or no fines.
		Gravels with Fines (> 12% fines)	GM		Silty gravels, gravel-sand-silt mixtures.
			GC		Clayey gravels, gravel-sand-clay mixtures.
	Sand and Sandy Soils More than 50% of coarse fraction passed no 4 sieve	Clean Sand (< 5% fines)	SW		Well-graded sands or gravelly sands, little or no fines Uc > 6 (lab only)
			SP		Poorly-graded sands or gravelly sands, little or no fines.
		Sands with Fines (> 12% fines)	SM		Silty sands sand-silt mixtures
			SC		Clayey sands, sand-clay mixtures.
Fine Grained Soils More than 50% of material is smaller than no 200 sieve size	Silts and Clays	Low Plasticity	ML		Inorganic silts and very fine sands, rock flour, silty or clayey fine sands, or clayey silts with slight plasticity
			CL		Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays.
			OL		Organic silts and organic silty clays of low plasticity
		High Plasticity	MH		Inorganic silts, micaceous or diatomaceous fine sand or silty soils
			CH		Inorganic clays of high plasticity, fat clays
			OH		Organic clays of medium to high plasticity, organic silts
Highly Organic Soils			PT		Peat, humus, swamp soils with high organic contents

Note Dual Symbols are used to indicate borderline soil classifications whose fines range from 5 to 12%

Unified Soil Classification System

Modified from "Water-Well Design and Construction, Development in Geotechnical Engineering, 60", by R L Harlan, K E Koln and E D Gutentag, Elsevier, 1989

(4011 930-0131 930)(Figure GT 1 2)(03/01/92)

- Color*
- Grain size
- Grading
- Angularity (ASTM D2488)
- Plasticity
- Composition
- Bedding
- Moisture content
- Top of bedrock, if present

* See Section 5 2 4 for guidelines on describing color For alluvial gravels, the color reported will be that of the matrix.

5.1.5 Problems With the U.S.C.S.

The following are problems that are intrinsic to the U S C S An obvious problem with the U S C S is that a change of one or two percent in coarse or fine material on either side of the 50 percent boundary may cause the sample classification to vary considerably For example, a clayey gravel (GC) or a clayey sand (SC) could easily change to a gravelly clay or a sandy clay with low plasticity (CL) or a sandy clay with high plasticity (CH) Clearly a classification system that is this sensitive is subject to errors, especially in the field

Another problem is that it is all but impossible to determine a liquid limit in the field For the purposes of this SOP, the liquid limit has been replaced by field estimate of plasticity (see Subsection 5 1 3) All loggers will refer to the ~~RFP~~ RFETS Alluvial Reference Set as an aide in making plasticity determinations

The U S C S also lacks the textural property of angularity that helps to determine the maturity of a sediment

Finally, the U S C S is a purely descriptive classification that has been designed for construction purposes and concentrates heavily on the physical properties of clay Because of this, the U S C S has 15 sample classifications and is very cumbersome

5.2 BEDROCK DESCRIPTIONS

All bedrock material should be classified and described by using many of the procedures and techniques described in Compton (1962), which has been incorporated with additional material in this SOP

5.2.1 Basis of Classification

Compton classifies sedimentary rocks on the basis of their texture, fabric, and composition Rock descriptions such as conglomerate, sandstone, siltstone, and shale (claystone and mudstone) are textural classifications based solely on grain size When other properties like sorting, roundness, bed thickness and contacts, cross-stratification, color, composition, cement, porosity, and fossil content are included, it is possible to make interpretations of where, how, and under what conditions the sediments were deposited

5.2.2 Textural Parameters

5.2.2.1 Grain Size Scale

The Wentworth grain size scale is divided into six main categories (1) cobbles, (2) pebbles, (3) granules, (4) sand, (5) silt, and (6) clay The pebble and sand categories are subdivided into very coarse, coarse, medium, and fine pebbles, and very coarse, coarse, medium, fine, and very fine sand (see Table GT 1-1) The scale is a geometric series with a base of 2

Unlike the U S C S in which the sand/silt boundary occurs at 0 074 mm, the sand/silt boundary occurs at 0 0625 mm in the Wentworth scale Since geotechnical laboratories generally plot grain size analyses on graph paper that is compatible with the U S C S , it is important to ensure that they also include the range of Wentworth grain size intervals on the graph paper (Figure GT 1-1) The grain size distribution of bedrock materials are made using the sieving techniques as described in Section 5 1 2 1

5.2.2.2 Degree of Sorting

Sorting is a measure of the extent to which a sediment has been winnowed or reworked during transport It also is a good indicator of the maturity of a sediment, the energy of the transporting agent, and the environment of deposition

In order to determine the degree of sorting, Compton (1962) states, "an estimate is made of the range of grain sizes that include the bulk (here 80 percent) of the detrital materials " It is then necessary to count the number of size ranges that are contained in the 80 percent sample (see Table GT 1-1) The number of size ranges is then compared with Figure GT 1-3 to determine the degree of sorting that describes the sample best

5.2.2.3 Degree of Rounding

Rounding is a measure of the amount of abrasion a grain has undergone However, it is <u>not</u> generally used to describe sediments that are much finer than sand, because grains finer than sand tend to have elastic collisions that do not affect the shape of the grain. Two properties that must be considered when estimating the degree of rounding are (1) the composition and (2) the original shape of the grain Rounding can be an indication of sediment maturity, sediment transport history and sometimes provenance The shapes shown in Figure GT 1-4 should be used to estimate the degree of rounding of individual grains

TERMS FOR DEGREE OF SORTING

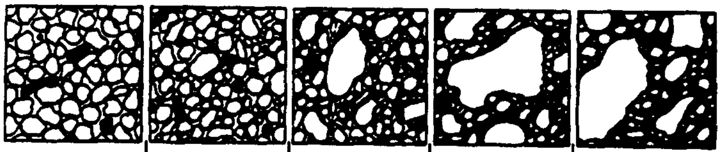


FIGURE GT.1-3

Terms for degrees of sorting The numbers indicate the number of size-classes included by the great bulk (80 percent) of the material The drawings represent sandstones as seen with a hand lens Silt and clay-size materials are shown diagramatically by the fine stipple Taken from Compton, 1962

TERMS FOR DEGREE OF ROUNDING

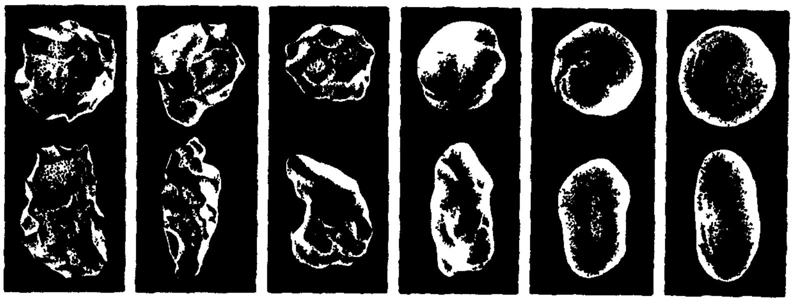


FIGURE GT.1-4

Terms for degree of rounding grains as seen with a hand lens After Powers, M C , 1953, "Journal of Sedimentary Petrology", v 23, p 118 Courtesy of the Society of Economic Paleontologists and Mineralogists Taken from Compton, 1962

5.2.2 4 Porosity

Porosity is not always an easy property to estimate in the field because the bedrock can be drastically altered during drilling and coring as well as by weathering Generally, samples exhibit more porosity than the rock actually contains

Porosity will be estimated at 20X using a binocular microscope and expressed as a percentage of the total rock volume The abundance charts shown in Figure GT 1-5 will be used The porosity seen at 20X power is an estimate of the effective aquifer porosity

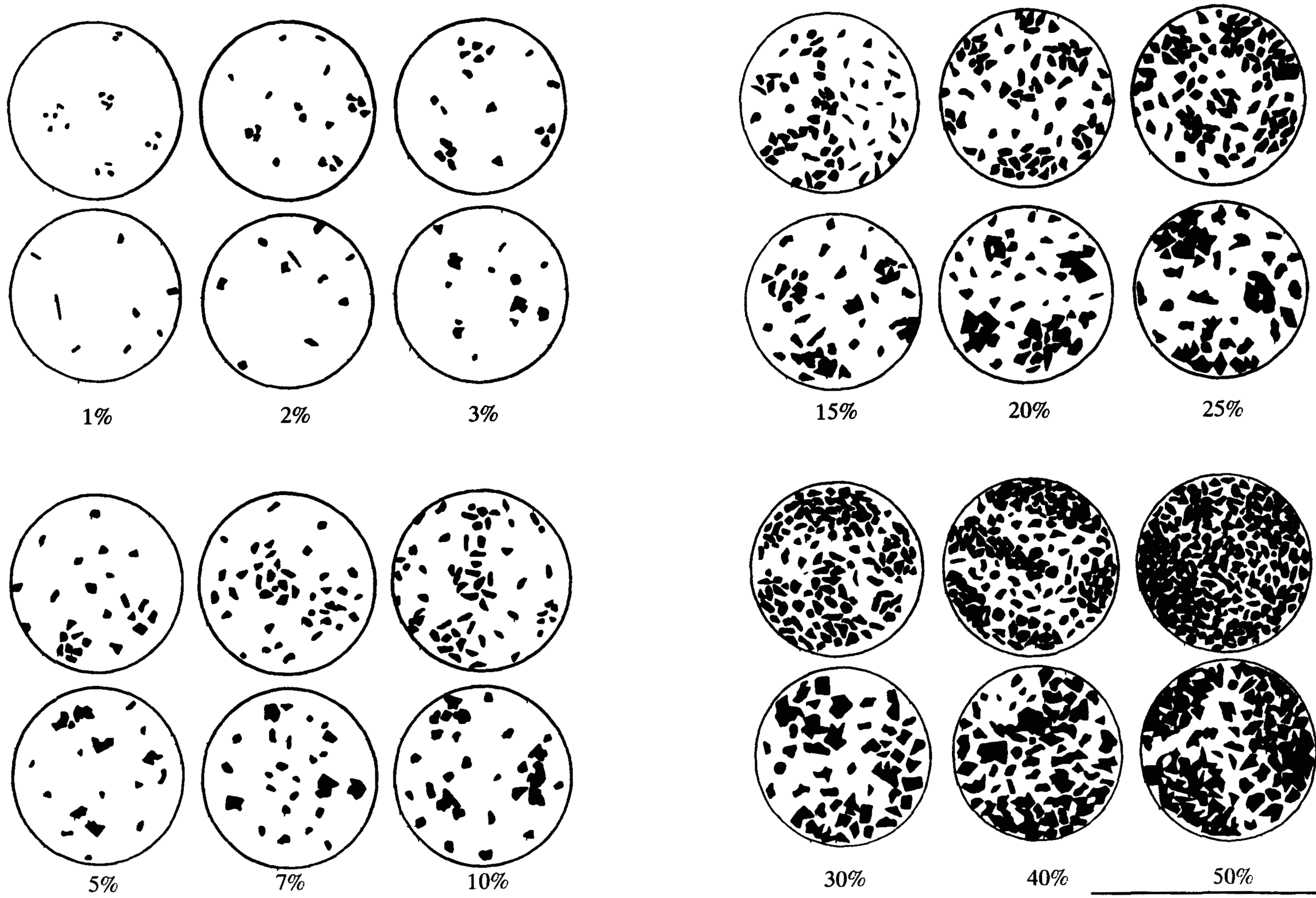
5.2.3 Estimate of Abundance

Figure GT 1-5 is composed of several drawings that represent the field of view commonly seen through a microscope or hand lens Each circle contains a number of black areas Below each circle is the actual percentage of black area that the circle contains All loggers should review Figure GT 1-5 until they are adept at estimating the percentages that are contained in the circles

5.2.3.1 Division of Abundance

Quite often it is necessary to determine the relative abundance of a variable In these cases, the use of the terms trace, some, and abundant has a utility The ranges for each are given in Table GT 1-2

CHARTS FOR ESTIMATING PERCENTAGE COMPOSITION OF ROCKS AND SEDIMENT



Prepared by R D Terry and G V Chilingar for "Journal of Sedimentary Petrology" (v 25, pp 229-234, 1955), reprinted as 'Data Sheet 6' of "Geotimes" available from the American Geological Institute, 2101 Constitution Ave , N W , Washington, D C Reprinted here by permission of the authors and the Society of Economic Paleontologists and Mineralologists Taken from Compton, 1962

FIGURE GT 1-5

TABLE GT 1-2
RANGE OF ABUNDANCE

Division	Range of Percent
Trace	>0 to 5
Some	6 to 25
Abundant	26 to 100

These terms generally follow a "with" statement, such as, Sandstone, light olive gray (5Y6/1), very fine to fine grained, with a trace of carbonaceous material

5.2.4 Color

Color can convey a great deal of information It helps to identify the components of the sediment or rock as well as the cement In addition, color is indicative of the current chemical environment from which the sample was taken For example, at ~~RFP~~ RFETS, highly weathered (oxidized) sandstones are commonly brownish-orange while unweathered sandstones are light olive grey

To ensure that the color descriptions are accurate and standardized, each sample should be described while it is wet by using the Geological Society of America "Rock-Color Chart" (1984) If the sample has dried, it should be moistened with clean water from a squirt bottle Care should also be taken to remove sunglasses when a color determination is being made

5.2.5 Rock Classification

Clastic rocks are primarily classified on the basis of their most frequent grain size The majority of rocks at ~~RFP~~ RFETS are claystone, siltstones, and sandstones, however, hybrids of these end members are quite common The second and sometimes third most frequent constituents act as modifiers and precede the major rock name in the description, such as, silty sandstone or clayey siltstone If, however, a rock is composed of 80 percent or more of one constituent, then it should be described solely as that rock type The secondary textural modifiers should then be described in the description following a "with" statement Figure GT 1-6 shows all the rock classifications and their lithologic symbols that should be used while logging bedrock samples

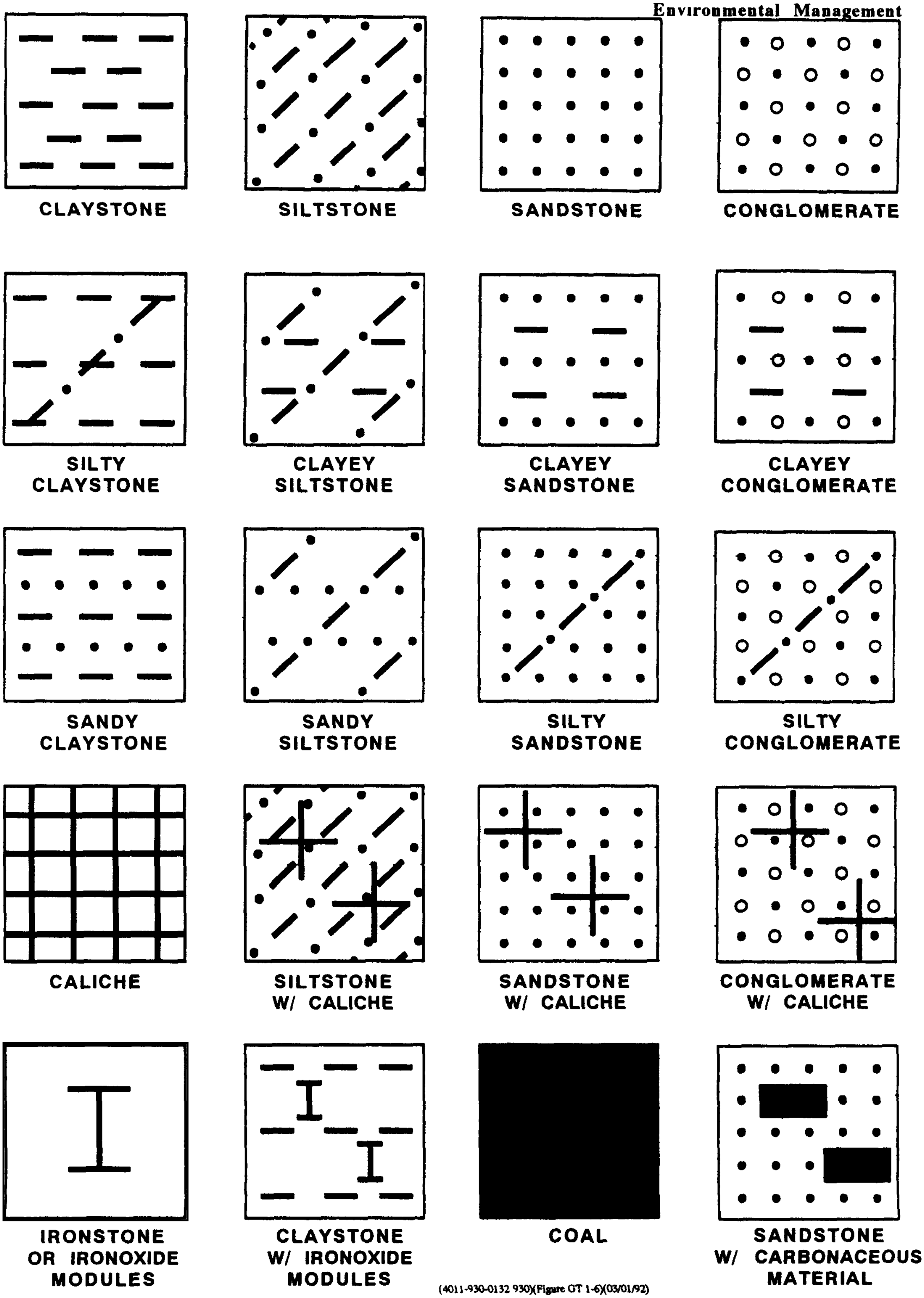
5.2.6 Cement

The nature of the cementing medium should be described whenever possible Typical cementing agents are clay (argillaceous cement), silica, and calcium carbonate (caliche)

5.2.7 Friability

The tendency of a rock to crumble is related to how well it is cemented and the extent to which it has been weathered Table GT 1-3 shows the degree of friability

FIGURE GT.1-6 LITHOLOGIC SYMBOLS FOR COMMON CLASTIC ROCKS



(4011-930-0132 930)(Figure GT 1-6)(03/01/92)

TABLE GT 1-3

DEGREE OF FRIABILITY

Term	Definition
Highly Friable	Crumbles readily into individual grains upon minor disturbance
Moderately Friable	Will crumble into individual grains with extensive rubbing
Slightly Friable	Can be broken into individual grains by scraping it with a pocket knife
Non-Friable	Cannot be broken into individual grains by any of the methods described above

5.2.8 Composition

It is not the objective of this SOP to classify sedimentary rocks on the basis of their mineral content by using tertiary diagrams with quartz/chert, feldspar, and lithic fragments at each pole Since Compton wrote the "Manual of Field Geology" in 1962, several classifications have been published Two of the most widely used classifications are those published by Earl McBride in 1963 and Robert Folk in 1974 Blatt, et al , (1972) presents an excellent evaluation of these and other classifications For the purpose of this SOP, the geologist is concerned with describing only accessory minerals, fossils, and other components that distinguish one rock from another The descriptive term(s) should follow a "with" statement, such as, silty sandstone, light olive grey (5Y6/1), very fine grained, with some pink feldspar rock fragments

5.2.9 Bedding and Internal Structure

In sedimentary rocks, bedding is related to differences in texture, composition, and color, and reflects changes in the environment of deposition and/or the source material Depending on the depositional processes that are involved, bedding boundaries may or may not represent a specific moment in time

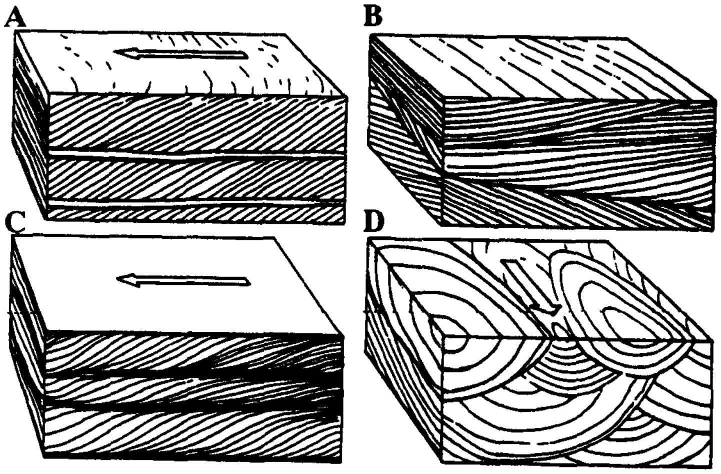
Compton classifies bedding as repeated sequences of beds, shapes of individual beds, and cross-bedding (cross-stratification) Repeated bedding is produced by cyclic changes in the sedimentary processes Individual bed shapes are classified as tabular, lenticular, linear, wedge-shaped, or irregular Cross-stratification is classified on the basis of its external and internal characteristics External forms of cross-stratification are tabular, wedge shaped, and trough shaped Internal descriptive terms that are commonly used are graded, massive, laminated, and tangential (Figure GT 1-7) Other internal features to be described include ripple marks, flow structures, burrows and tubes, load casts, and desiccation cracks (mud cracks)

5.2.10 Fractures and Slickensides

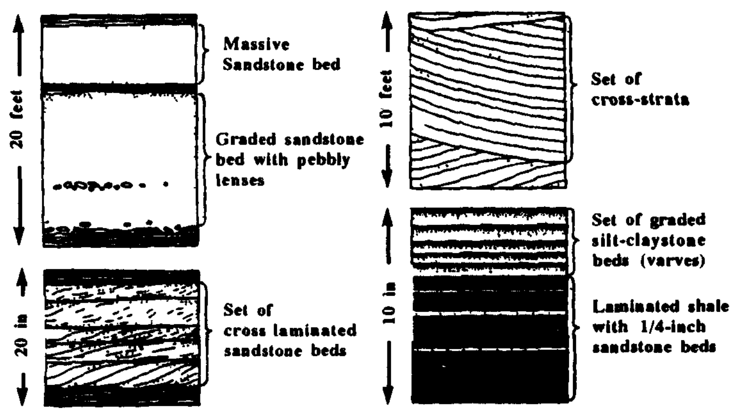
Fractures should be described whenever they are present Fractures occur naturally in bedrock and should not be confused with breaks induced by coring and handling The characteristics that should be noted about the fracture are

- Whether the fracture is opened or healed
- The composition of the material filling the fracture, if any
- The angle of the fracture from the horizontal
- The apparent displacement of bedding across the fracture
- Whether slickensides are present and the angle of any striations from the horizontal

BEDDING AND INTERNAL STRUCTURES



Cross-bedded rocks (A) Tabular sets with diagonal patterns (B) Wedge sets, showing considerable erosion between each set (C) Tabular to lenticular sets with tangential patterns, typically, these are laminated marine beds (D) Symmetrical trough sets with distinctly linear axes, typically, these are large-scale fluvial features The arrows indicate current directions Taken from Compton, 1962



Various beds and sets of beds Taken from Compton, 1962

FIGURE GT.1-7

5.2.11 Moisture Content

The core will be described as dry, moist, or saturated, and the depth to the top of the saturated interval will be recorded If a static water level can be measured, it will be noted The moisture content and static water level (if present) will be recorded in the field on the back of the core logging form The core logger will include this information in the core description

5.2.12 Lithologic Description

Generally, lithologic descriptions should be made in the following order

- Top of bedrock, if present
- Main rock type with modifiers
- Color
- Grain size
- Degree of sorting
- Degree of rounding
- Porosity
- Cement
- Friability
- Composition
- Bedding and internal structure
- Fractures and slickensides
- Moisture content

6.0 LOGGING

This section describes the field procedures used while logging

It is the responsibility of the logging personnel to ensure that all of the materials and equipment needed for logging are at the site

6.1 LOGGING EQUIPMENT

The following is a list of equipment that is necessary to properly log the alluvial and bedrock material

- Core Reference Set
- Alluvial Reference Set
- Rock-Color Chart
- Logging forms
- Hand lens
- Nos 4, 10, 40, 200, and 230 sieves (8-inch) with lid and base
- Six-foot metal tape measure in tenths of a foot
- Core boxes (2 feet long, 5 columns each 2-1/2 inches wide) (such as, Boise Cascade No 17-505 top and bottom)
- Wood blocks (2-1/2 inches x 3/4 inches) for marking depths and sample locations
- Jars for cuttings
- Wentworth and/or Amstrat grain size charts
- Knife
- Acid (10 percent HCl) in squirt bottle
- Water in squirt bottle
- Black waterproof (permanent) markers and pens
- Protective clothing and equipment (see Health & Safety Plan)

- Flashlight
- Hammer
- Clipboard
- Table
- Duct tape
- Paper towels
- Plastic wrap
- Protractor
- Camera (35 mm) with film (Kodak color patch)
- Flat-bladed screwdriver
- Awl
- Binocular microscope
- Mortar and pestal
- Hot plate
- Spot plate
- 500 ml beakers
- 10 ml and 50 ml graduated cylinders
- Watch glass

6.2 CORES AND CUTTINGS

6.2.1 Scanning the Core

After an interval of core has been cut and the sampler has been opened, the core will be scanned for hazardous and radioactive contamination The field use of monitors for the detection of volatile organics and radionuclides is discussed in SOPs FO 8, Handling of Drilling Fluids and Cuttings, FO 15, Photoionization Detectors (PIDs) and Flame Ionization Detectors (FIDs), and FO 16, Field Radiological Measurements Once the core has been scanned, it will be handled in accordance with the Health and Safety Plan See Section 6 3, Core Boxes for a discussion on isolating core sections that are suspected of containing radioactive and/or hazardous substances

6.2.2 Percent Recovery

The core should be consolidated in the sampler, measured to the nearest tenth of a foot, and if competent, etched with two parallel lines using an awl and a flat-bladed screwdriver The awl line will be etched on the left side of the core, for the entire length of the core The screwdriver line will be etched on the right side of the core, for the entire length of the core These etched lines denote the "up" position All competent core will be etched with enough pressure so the lines are readily visible, but not with enough pressure so the core's features are obliterated or altered Once etched, the core will be slid out onto the plastic wrap that has been placed in the core box The interval drilled and the interval recovered will be recorded on the logging form Figure GT 1-8 is an example of a completed logging form Wood blocks with footage values marked on them in black waterproof ink will be placed at each end of each core run Intervals of no recovery should be recorded on wooden blocks and placed at appropriate locations in the core box. If only cuttings were collected, a representative sample will be collected every 2 feet, unless drilling rates and/or depth constraints make this impractical in which case 5-foot samples will be collected The EG&G project manager will determine the collection interval The samples will be placed in labeled jars in the core box.

If the cores or drill cuttings are logged at a separate location removed from the drill site, the following information will be recorded on Form GT 1B (located on the back of Form GT 1B) generalized lithologic descriptions, moisture content, depth to water table, and all geochemical and geotechnical sample numbers with corresponding sampling depths Cores and logging forms will be delivered to the remote location within one day of filling each core box. The first four columns of the log will either be filled out in the field, or the information to properly fill out the columns will be provided on Form GT 1B

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6.2.3 Logging

The core or cuttings will be logged according to all of the procedures previously covered in this SOP

6.2.4 Photographing the Core

Any and all photographing procedures must conform to plant security controls Each box of core should be photographed with a 35 mm camera before it has been logged and sampled If the core is photographed at RFP, the camera will have to be cleared and left on site until the project is completed In addition, all of the film must be processed by ~~RFP~~ RFETS An identification tag and a Kodak color patch should appear in each photograph The identification tag should contain

- The well name
- Footage values of the core in the box
- The box number and the total number of boxes for that borehole, such as Box 1 of 7
- Date core was taken
- Project number

6.2.5 Sampling

Samples that are taken for grain size analyses and permeameter tests should be removed only after the core has been logged and photographed At the time a sample is taken, a wood block with the following information must be placed in the core box at the point the sample was removed

- Sample number
- Depth
- Purpose
- Date
- Company

This information will be marked on the wood block with a black waterproof (permanent) marker

6.3 CORE BOXES

The core boxes will be similar to the boxes described in Subsection 6 1 above Each core box and lid will be marked with the following information

- Well name
- Depth interval
- Date
- Project name
- Well site geologist's initials
- Logger's initials (after logging is completed)
- Box number and the total number of boxes
- Appropriate hazardous waste labels

After samples have been scanned as discussed in Subsection 6 2 1, the core will be containerized Radiation and volatile organic analysis (VOA) readings will be written on the tops of the core boxes Sections of the core suspected of containing radioactive and/or hazardous substances will be removed, segregated by their potential contaminant characterization, and placed in core boxes designated for potentially contaminated core The remaining core will then be placed in separate core boxes Wood blocks will be placed within the core boxes to indicate the position where potentially contaminated core sections were removed Blocks will be marked with the interval of the core section removed and where the section can be located

The core boxes will be closed and secured in a manner such that core will not be disturbed or mislocated during transportation Core boxes suspected of containing low-level radioactive substances will be labeled with a "White I" radioactive label Core boxes suspected of containing volatile organic or mixed substances will be labeled with a Department of Transportation "Other Regulated Material Class E" (ORM-E) label (see SOP FO 10, Receiving, Labeling, and Handling Environmental Materials Containers) If the suspected contamination is mixed substances, the core box will also be marked with the words "SUS RAD" for suspected radioactive contamination

Core boxes suspected of containing radioactive and/or hazardous substances will be stored in a facility designated for potentially contaminated core All other core boxes will be stored at the main core storage facility at ~~RFP~~ RFETS

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7.0 DOCUMENTATION

A permanent record of the implementation of this SOP will be kept by documenting all information required by the SOP on the Borehole Log Form (Form GT 1A) Drilling activities will also be documented on the hollow-stem auger or rotary and core drilling Field Activities Report Forms (see SOP GT 2, Drilling and Sampling Using Hollow-Stem Auger Techniques, and SOP GT 4, Rotary Drilling and Rock Coring)

The logger will primarily be responsible for each aspect and each procedure

APPENDIX GT.1A

UNIFIED SOIL CLASSIFICATION SYSTEM

CHARACTERISTICS OF SOIL GROUPS

PERTAINING TO EMBANKMENTS AND FOUNDATIONS

ROCKY FLATS PLANT BOREHOLE LOG

PAGE ____ OF ____

Borehole Number ______________________ Surface Elevation ______________________

Location - North __________ East __________ Area ______________________

Date ______________________ Total Depth __________

Geologist ______________________ Company __________ Project No __________

Drilling Equip ______________________ Sample Type ______________________

[redacted] LOGGING SUPERVISOR

APPROVAL ______________________ DATE ______________________

TOP/BOTTOM OF CORE IN BOX	TOP/BOTTOM OF INTERVAL	FEET OF CORE IN INTERVAL (FIELD MEASUREMENT)	SAMPLE NUMBER	FRACTURE ANGLE	BEDDING ANGLE	GRAIN SIZE DISTRIBUTION	USCS SYMBOL	DEPTH IN FEET	SOIL/ LITHOLOGIC LOG	SAMPLE DESCRIPTION

NOTES General USCS is modified for this log as follows
Materials amounts are estimated by % volume instead of % weight
(1) Badly broken core, accurate footage measurements not possible
(2) Core breaks cannot be matched, accurate footage measurements not possible

ROCKY FLATS PLANT BOREHOLE LOG

PAGE 2 OF 7

Borehole Number Well or BH Number
Location - North 749718.7 East 2086747.7
Date 11/17/91
Geologist JBP/Stratigrapher Initials
Drilling Equip CME 75

Surface Elevation 5962 ft
Area East Trenches
Total Depth 72.Φ ft
Company Subcontractor Project No OU #
Sample Type Continuous Core

[redacted] LOGGING SUPERVISOR
APPROVAL ______ DATE ______

TOP/BOTTOM OF CORE IN BOX	TOP/BOTTOM OF INTERVAL	FEET OF CORE IN INTERVAL (FIELD MEASUREMENT)	SAMPLE NUMBER	FRACTURE ANGLE	BEDDING ANGLE	GRAIN SIZE DISTRIBUTION	USCS SYMBOL	DEPTH IN FEET	SOIL/ LITHOLOGIC LOG	SAMPLE DESCRIPTION
1Φ Φ	1Φ Φ Run6 12 Φ	1Φ Φ 2 Φ'	Sample Number			Gravel 37% Sand 52% Silt 7% Clay 4%	SM	1Φ 11 12		SM-SW 1Φ Φ'-12 7' Gravelly Sand Dark yellowish brown (1Φ YR 4/2) to moderate yellowish brown (1ΦYR 5/4) Sand: coarse grained, subangular Gravel: avg. size = Φ 5 inches max. size = 1Φ inch subangular to angular Well graded; sand predom Quartz; gravel predom Qua e and feldspar alcite; dry
Box 2 of 8 1Φ.Φ'-16.5'	Run 7 14.Φ	1 9'	Sample Number V 8					13 14		
	Run8 16.5	4.3'	Sample Number C			Sand 4Φ% Silt 4		16		14 Φ'-16.5' Sandy Clay with trace of silt Dusky yellowish brown (1Φ YR 2/2) to dark yellowish brown (1Φ YR 4/2) Sand: fine grained; subangular Low plasticity; dry Top of Bedrock at 16.5'
16.5			Sample Number			>95% Clay		17 18		Claystone 16 5'-2Φ.5' Dusky yellowish brown (1Φ YR 4/2) Some carbonaceous material; moderately friable; moist
Box 3 of 8 16 5'-22.Φ'	19.Φ		Sample Number V 8 C					19 2Φ		

EXAMPLE

NOTES General USCS is modified for this log as follows
Materials amounts are estimated by % volume instead of % weight
(1) Badly broken core, accurate footage measurements not possible
(2) Core breaks cannot be matched, accurate footage measurements not possible

(4011 930-0134-930)(Form GT 1A)(03/01/92)

FIGURE GT.1-8

APPENDIX GT.1B

UNIFIED SOIL CLASSIFICATION SYSTEM

CHARACTERISTICS OF SOIL GROUPS

PERTAINING TO ROADS AND AIRFIELDS

UNIFIED SOIL CLASSIFICATION SYSTEM

APPENDIX B

CHARACTERISTICS OF SOIL GROUPS PERTAINING TO ROADS AND AIRFIELDS

Introduction

1. The properties desired in soils for foundations under roads and airfields and for base courses under flexible pavements are: adequate strength, good compaction characteristics, adequate drainage, resistance to frost action in areas where frost is a factor, and acceptable compression and expansion characteristics. Certain of these properties, if inadequate in the soils available, may be supplied by proper construction methods. For instance, materials having good drainage characteristics are desirable, but if such materials are not available locally, adequate drainage may be obtained by installing a properly designed water collecting system. Strength requirements for base course materials, to be used immediately under the pavement of a flexible pavement structure, are high and only good quality materials are acceptable. However, low strengths in subgrade materials may be compensated for in many cases by increasing the thickness of overlying concrete pavement or of base materials in flexible pavement construction. From the foregoing brief discussion, it may be seen that the proper design of roads and airfield pavements requires the evaluation of soil properties in more detail than is possible by use of the general soils classification system. However, the grouping of soils in the classification system is such that a general indication of their behavior in road and airfield construction may be obtained.

Features Shown on Soils Classification Sheet

2. General characteristics of the soil groups pertinent to roads and airfields are presented in table B1. Columns 1 through 5 show major

soil divisions, group symbols, hatching and color symbols, column 6 gives names of soil types, column 7 evaluates the performance (strength) of the soil groups when used as subgrade materials that will not be subject to frost action, column 8 and column 9 make a similar evaluation for the soils when used as subbase and base materials; potential frost action is shown in column 10, compressibility and expansion characteristics are shown in column 11, column 12 presents drainage characteristics, column 13 shows types of compaction equipment that perform satisfactorily on the various soil groups; column 14 shows ranges of unit dry weight for compacted soils, column 15 gives ranges of typical California Bearing Ratio (CBR) values, and column 16 gives ranges of modulus of subgrade reaction (k). The various features presented are discussed in the following paragraphs.

Subdivision of
coarse-grained soil groups

3. It will be noted in column 3, letter symbols, that the basic soil groups, GM and SM, have each been subdivided into two groups designated by the suffixes d and u which have been chosen to represent desirable and less desirable (undesirable) base materials, respectively. This subdivision applies to roads and airfields only and is based on field observation and laboratory tests on the behavior of the soils in these groups. Basis for the subdivision is the liquid limit and plasticity index of the fraction of the soil passing the No. 40 sieve. The suffix d is used when the liquid limit is 25 or less and the plasticity index is 5 or less; the suffix u is used otherwise. Typical symbols for soils in these groups are GMd and SMu, etc.

Values of soils as subgrade,
subbase, or base materials

4. The descriptions in columns 7, 8, and 9 give a general indication of the suitability of the soil groups for use as subgrades, subbase, or base materials, provided they are not subject to frost action. In areas where frost heaving is a problem, the value of materials as subgrades or subbases will be reduced, depending on the potential frost action of the material, as shown in column 10. Proper design procedures

APPENDIX GT.1B

UNIFIED SOIL CLASSIFICATION SYSTEM

CHARACTERISTICS OF SOIL GROUPS

PERTAINING TO ROADS AND AIRFIELDS

test values should be used for this purpose instead of the approximate values shown in the tabulation.

5. For wearing surfaces on unsurfaced roads sand-clay-gravel mixtures (GC) are generally considered the most satisfactory. However, they should not contain too large a percentage of fines and the plasticity index should be in the range of 5 to about 15.

Potential frost action

6. The relative effects of frost action on the various soil groups are shown in column 10. Regardless of the frost susceptibility of the various soil groups two conditions must be present simultaneously before frost action will be a major consideration. These are a source of water during the freezing period and a sufficient period for the freezing temperature to penetrate the ground. Water necessary for the formation of ice lenses may become available from a high ground-water table, capillary supply, water held within the soil voids, or through infiltration. The degree of ice formation that will occur in any given case is markedly influenced by environmental factors such as topographic position, stratification of the parent soil, transitions into cut sections, lateral flow of water from side cuts, localized pockets of perched ground water, and drainage conditions. In general, the silts and fine silty sands are the worst offenders as far as frost is concerned. Coarse-grained materials with little or no fines are affected only slightly if at all. Clays (CL and CH) are subject to frost action, but the loss of strength of such materials may not be as great as for silty soils. Inorganic soils containing less than three per cent of grains finer than 0.02 mm in diameter by weight are generally nonfrost-susceptible. Where frost-susceptible soils are encountered in subgrades and frost is a definite problem, two acceptable methods of design of pavements are available. Either a sufficient depth of acceptable granular material is placed over the soils to prevent freezing in the subgrade and thereby prevent the detrimental effects of frost action, or a reduced depth of granular material is used, thereby allowing freezing in the subgrade, and design is based on the reduced strength of the subgrade during the frost-melting period. In many cases appropriate drainage measures to prevent the accumulation of

UNIFIED SOIL CLASSIFICATION SYSTEM

APPENDIX B

CHARACTERISTICS OF SOIL GROUPS PERTAINING TO ROADS AND AIRFIELDS

Introduction

1. The properties desired in soils for foundations under roads and airfields and for base courses under flexible pavements are adequate strength, good compaction characteristics, adequate drainage, resistance to frost action in areas where frost is a factor, and acceptable compression and expansion characteristics. Certain of these properties, if inadequate in the soils available, may be supplied by proper construction methods. For instance, materials having good drainage characteristics are desirable, but if such materials are not available locally, adequate drainage may be obtained by installing a properly designed water collecting system. Strength requirements for base course materials, to be used immediately under the pavement of a flexible pavement structure, are high and only good quality materials are acceptable. However, low strengths in subgrade materials may be compensated for in many cases by increasing the thickness of overlying concrete pavement or of base materials in flexible pavement construction. From the foregoing brief discussion, it may be seen that the proper design of roads and airfield pavements requires the evaluation of soil properties in more detail than is possible by use of the general soils classification system. However, the grouping of soils in the classification system is such that a general indication of their behavior in road and airfield construction may be obtained.

Features Shown on Soils Classification Sheet

2. General characteristics of the soil groups pertinent to roads and airfields are presented in table B1. Columns 1 through 5 show major

should be used in situations where this is a problem. The coarse-grained soils in general are the best subgrade, subbase, and base materials. The GW group has excellent qualities as a subgrade and subbase, and is good as base material. It is noted that the adjective "excellent" is not used for any of the soils for base courses, it is considered that the adjective "excellent" should be used in reference to a high quality processed crushed stone. Poorly-graded gravels and some silty gravels, groups GP and GMd, are usually only slightly less desirable as subgrade or subbase materials, and under favorable conditions may be used as base materials for certain conditions, however, poor gradation and other factors sometimes reduce the value of such soils to such extent that they offer only moderate strength and therefore their value as a base material is less. The GMu, GC, and SW groups are reasonably good subgrade materials, but are generally poor to not suitable as bases. The SP and SMd soils usually are considered fair to good subgrade and subbase materials but in general are poor to not suitable for base materials. The SMu and SC soils are fair to poor subgrade and subbase materials, and are not suitable for base materials. The fine-grained soils range from fair to very poor subgrade materials as follows: silts and lean clays (ML and CL), fair to poor, organic silts, lean organic clays, and micaceous or diatomaceous soils (OL and MH), poor, fat clays and fat organic clays (CH and OH), poor to very poor. These qualities are compensated for in flexible pavement design by increasing the thickness of overlying base material, and in rigid pavement design by increasing the pavement thickness or by the addition of a base course layer. None of the fine-grained soils are suitable as subbase or base materials. The fibrous organic soils (group Pt) are very poor subgrade materials and should be removed wherever possible; otherwise, special construction measures should be adopted. They are not suitable as subbase and base materials. The California Bearing Ratio (CBR) values shown in column 15 give a relative indication of the strength of the various soil groups as used in flexible pavement design. Similarly, values of subgrade modulus (k) in column 16 are relative indications of strengths from plate-bearing tests as used in rigid pavement design. As these tests are used for the design of pavements, actual test values should be used for this purpose instead of the approximate values shown in the tabulation.

5. For wearing surfaces on unsurfaced roads sand-clay-gravel mixtures (GC) are generally considered the most satisfactory. However, they should not contain too large a percentage of fines and the plasticity index should be in the range of 5 to about 15.

Potential frost action

6. The relative effects of frost action on the various soil groups are shown in column 10. Regardless of the frost susceptibility of the various soil groups two conditions must be present simultaneously before frost action will be a major consideration. These are a source of water during the freezing period and a sufficient period for the freezing temperature to penetrate the ground. Water necessary for the formation of ice lenses may become available from a high ground-water table, capillary supply, water held within the soil voids, or through infiltration. The degree of ice formation that will occur in any given case is markedly influenced by environmental factors such as topographic position, stratification of the parent soil, transitions into cut sections, lateral flow of water from side cuts, localized pockets of perched ground water, and drainage conditions. In general, the silts and fine silty sands are the worst offenders as far as frost is concerned. Coarse-grained materials with little or no fines are affected only slightly if at all. Clays (CL and CH) are subject to frost action, but the loss of strength of such materials may not be as great as for silty soils. Inorganic soils containing less than three per cent of grains finer than 0.02 mm in diameter by weight are generally nonfrost-susceptible. Where frost-susceptible soils are encountered in subgrades and frost is a definite problem, two acceptable methods of design of pavements are available. Either a sufficient depth of acceptable granular material is placed over the soils to prevent freezing in the subgrade and thereby prevent the detrimental effects of frost action, or a reduced depth of granular material is used, thereby allowing freezing in the subgrade, and design is based on the reduced strength of the subgrade during the frost-melting period. In many cases appropriate drainage measures to prevent the accumulation of

water in the soil pores will help to diminish ice segregation in the subgrade and subbase.

Compressibility and expansion

7. These characteristics of soils may be of two types insofar as their applicability to road and runway design is concerned. The first is the relatively long-term compression or consolidation under the dead weight of the structure, and the second is the short-term compression and rebound under moving wheel loads. The long-term consolidation of soils becomes a factor in design primarily when heavy fills are made on compressible soils. If adequate provision is made for this type of settlement during construction it will have little influence on the load-carrying capacity of the pavement. However, when elastic soils subject to compression and rebound under wheel load are encountered, adequate protection must be provided, as even small movements of this type soil may be detrimental to the base and wearing course of pavements. It is fortunate that the free-draining, coarse-grained soils (GW, GP, SW, and SP), which in general make the best subgrade and subbase materials, exhibit almost no tendency toward high compressibility or expansion. In general, the compressibility of soils increases with increasing liquid limit. The foregoing is not completely true, as compressibility is also influenced by soil structure, grain shape, previous loading history, and other factors that are not evaluated in the classification system. Undesirable compressibility or expansion characteristics may be reduced by distribution of load through a greater thickness of overlying material. This, in general, is adequately handled by the CBR method of design for flexible pavements; however, rigid pavements may require the addition of an acceptable base course under the pavement.

Drainage characteristics

8. The drainage characteristics of soils are a direct reflection of their permeability. The evaluation of drainage characteristics for use in roads and runways is shown in column 12. The presence of moisture in base, subbase, and subgrade materials, except for free-draining, coarse-grained soils, may cause the development of pore water pressures and loss of strength. The moisture may come from infiltration of rain water or by

MIL-STD-621A. These values are included primarily for guidance design or control of construction should be based on test results

Graphical Presentation of Soils Data

10. It is customary to present the results of soils explorations on drawings as schematic representations of the borings or test pits or on soil profiles with the various soils encountered shown by appropriate symbols As one approach, the group letter symbol (CL, etc.) may be written in the appropriate section of the log. As an alternative, hatching symbols shown in column 4 of table B1 may be used. In addition, the natural water content of fine-grained soils should be shown along the side of the log. Other descriptive abbreviations may be used as deemed appropriate. In certain special instances the use of color to delineate soil types on maps and drawings is desirable. A suggested color scheme to show the major soil groups is described in column 5 of table B1.

Designation D 422 – 63 (Reapproved 1972)[ε1]

Standard Method for Particle-Size Analysis of Soils[1]

This standard is issued under the fixed designation D 422 the number immediately following the designation indicates the year of original adoption or in the case of revision the year of last revision A number in parentheses indicates the year of last reapproval A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval

ε1 NOTE—Section 2 was added editorially and subsequent sections renumbered in July 1984

1 Scope

1 1 This method covers the quantitative determination of the distribution of particle sizes in soils The distribution of particle sizes larger than 75 µm (retained on the No 200 sieve) is determined by sieving, while the distribution of particle sizes smaller than 75 µm is determined by a sedimentation process, using a hydrometer to secure the necessary data (Notes 1 and 2)

NOTE 1—Separation may be made on the No 4 (4 75-mm), No 40 (425-µm), or No 200 (75-µm) sieve instead of the No 10 For whatever sieve used, the size shall be indicated in the report.

NOTE 2—Two types of dispersion devices are provided (*1*) a high-speed mechanical stirrer and (*2*) air dispersion Extensive investigations indicate that air-dispersion devices produce a more positive dispersion of plastic soils below the 20-µm size and appreciably less degradation on all sizes when used with sandy soils. Because of the definite advantages favoring air dispersion, its use is recommended. The results from the two types of devices differ in magnitude, depending upon soil type, leading to marked differences in particle size distribution, especially for sizes finer than 20 µm.

2. Referenced Documents

2 1 *ASTM Standards*

D 421 Practice for Dry Preparation of Soil Samples for Particle-Size Analysis and Determination of Soil Constants[2]

E 11 Specification for Wire-Cloth Sieves for Testing Purposes[3]

E 100 Specification for ASTM Hydrometers[4]

3 Apparatus

3 1 *Balances*—A balance sensitive to 0 01 g for weighing the material passing a No 10 (2 00-mm) sieve, and a balance sensitive to 0 1 % of the mass of the sample to be weighed for weighing the material retained on a No 10 sieve

3 2 *Stirring Apparatus*—Either apparatus A or B may be used

3 2 1 Apparatus A shall consist of a mechanically operated stirring device in which a suitably mounted electric motor turns a vertical shaft at a speed of not less than 10 000 rpm without load The shaft shall be equipped with a replaceable stirring paddle made of metal plastic or hard rubber as shown in Fig 1 The shaft shall be of such length that the stirring paddle will operate not less than ¾ in (19 0 mm) nor more than 1½ in (38 1 mm) above the bottom of the dispersion cup A special dispersion cup conforming to either of the designs shown in Fig. 2 shall be provided to hold the sample while it is being dispersed

3 2 2 Apparatus B shall consist of an air-jet dispersion cup[5] (Note 3) conforming to the general details shown in Fig 3 (Notes 4 and 5)

NOTE 3—The amount of air required by an air-jet dispersion cup is of the order of 2 ft^3/min some small air compressors are not capable of supplying sufficient air to operate a cup

NOTE 4—Another air-type dispersion device known as a dispersion tube developed by Chu and Davidson at Iowa State College has been shown to give results equivalent to those secured by the air-jet dispersion cups When it is used, soaking of the sample can be done in the sedimentation cylinder, thus eliminating the need for transferring the slurry When the air-dispersion tube is used, it shall be so indicated in the report

NOTE 5—Water may condense in air lines when not in use This water must be removed, either by using a water trap on the air line, or by blowing the water out of the line before using any of the air for dispersion purposes.

3 3 *Hydrometer*—An ASTM hydrometer, graduated to read in either specific gravity of the suspension or grams per litre of suspension and conforming to the requirements for hydrometers 151H or 152H in Specifications E 100 Dimensions of both hydrometers are the same, the scale being the only item of difference

3 4 *Sedimentation Cylinder*—A glass cylinder essentially 18 in (457 mm) in height and 2½ in (63 5 mm) in diameter and marked for a volume of 1000 mL. The inside diameter shall be such that the 1000-mL mark is 36 ± 2 cm from the bottom on the inside

3 5 *Thermometer*—A thermometer accurate to 1°F (0 5°C)

3 6 *Sieves*—A series of sieves, of square-mesh woven-wire cloth conforming to the requirements of Specification E 11 A full set of sieves includes the following (Note 6)

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[1] This method is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18 03 on Texture, Plasticity and Density Characteristics of Soils.

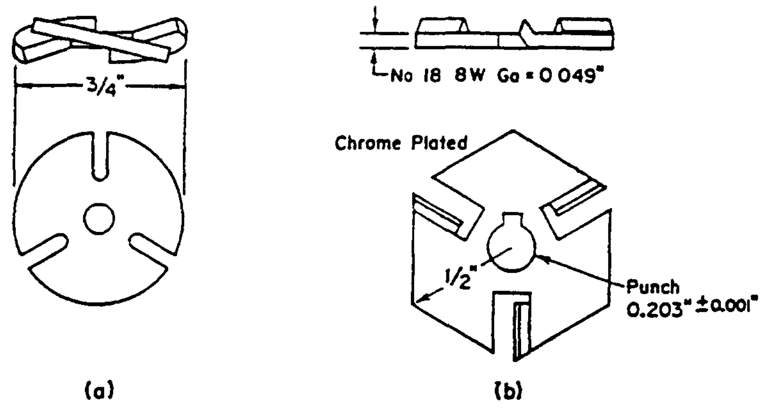
Current edition approved Nov 21 1963 Originally published 1935 Replaces D 422 – 62

[2] *Annual Book of ASTM Standards* Vol 04 08

[3] *Annual Book of ASTM Standards* Vol 14 02.

[4] *Annual Book of ASTM Standards* Vol 14 01

[5] Detailed working drawings for this cup are available at a nominal cost from the American Society for Testing and Materials, 1916 Race St., Philadelphia PA 19103 Order Adjunct No 12-404220-00



Metric Equivalents

in	0 001	0 049	0 203	½	¾
mm	0 03	1.24	5 16	12 7	19 0

FIG 1 Detail of Stirring Paddles

3-in (75-mm)	No 10 (2 00-mm)
2-in (50-mm)	No 20 (850-µm)
1½-in (37 5 mm)	No 40 (425-µm)
1-in (25 0-mm)	No 60 (250-µm)
¾-in (19 0-mm)	No 140 (106-µm)
⅜-in. (9 5-mm)	No 200 (75-µm)
No 4 (4 75-mm)	

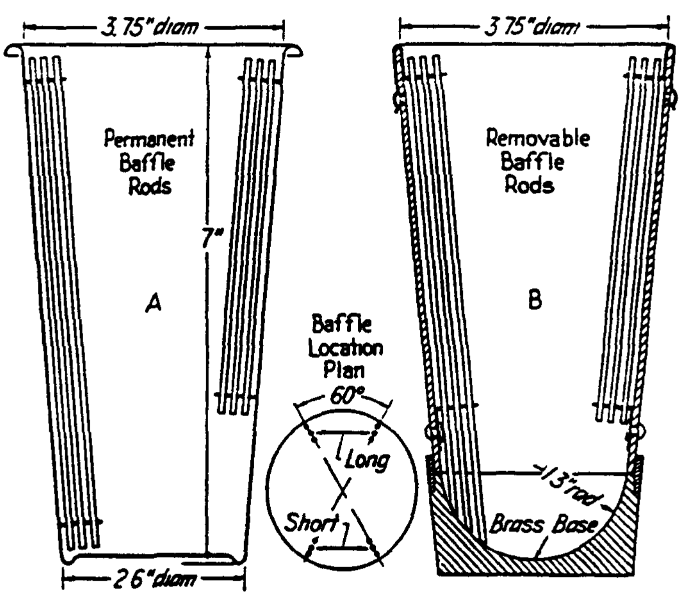
NOTE 6—A set of sieves giving uniform spacing of points for the graph, as required in Section 17, may be used if desired. This set consists of the following sieves:

3-in (75-mm)	No 16 (1 18-mm)
1½-in (37 5-mm)	No 30 (600-µm)
¾-in (19 0-mm)	No 50 (300-µm)
⅜-in (9 5-mm)	No 100 (150-µm)
No 4 (4 75-mm)	No 200 (75-µm)
No 8 (2 36-mm)	

3 7 *Water Bath or Constant-Temperature Room*—A water bath or constant-temperature room for maintaining the soil suspension at a constant temperature during the hydrometer analysis A satisfactory water tank is an insulated tank that maintains the temperature of the suspension at a convenient constant temperature at or near 68°F (20°C) Such a device is illustrated in Fig. 4 In cases where the work is performed in a room at an automatically controlled constant temperature, the water bath is not necessary

3 8 *Beaker*—A beaker of 250-mL capacity

3 9 *Timing Device*—A watch or clock with a second hand



Metric Equivalents

in.	1.3	2.6	3 75
mm	33	66	95.2

FIG. 2 Dispersion Cups of Apparatus

4. Dispersing Agent

4 1 A solution of sodium hexametaphosphate (sometimes called sodium metaphosphate) shall be used in distilled or demineralized water, at the rate of 40 g of sodium hexametaphosphate/litre of solution (Note 7)

NOTE 7—Solutions of this salt, if acidic, slowly revert or hydrolyze back to the orthophosphate form with a resultant decrease in dispersive action Solutions should be prepared frequently (at least once a month) or adjusted to pH of 8 or 9 by means of sodium carbonate Bottles containing solutions should have the date of preparation marked on them

4 2 All water used shall be either distilled or demineralized water The water for a hydrometer test shall be brought to the temperature that is expected to prevail during the hydrometer test. For example, if the sedimentation cylinder is to be placed in the water bath, the distilled or demineralized water to be used shall be brought to the temperature of the controlled water bath, or, if the sedimentation cylinder is used in a room with controlled temperature, the water for the test shall be at the temperature of the room The basic temperature for the hydrometer test is 68°F (20°C) Small variations of temperature do not introduce differences that are of practical significance and do not prevent the use of corrections derived as prescribed

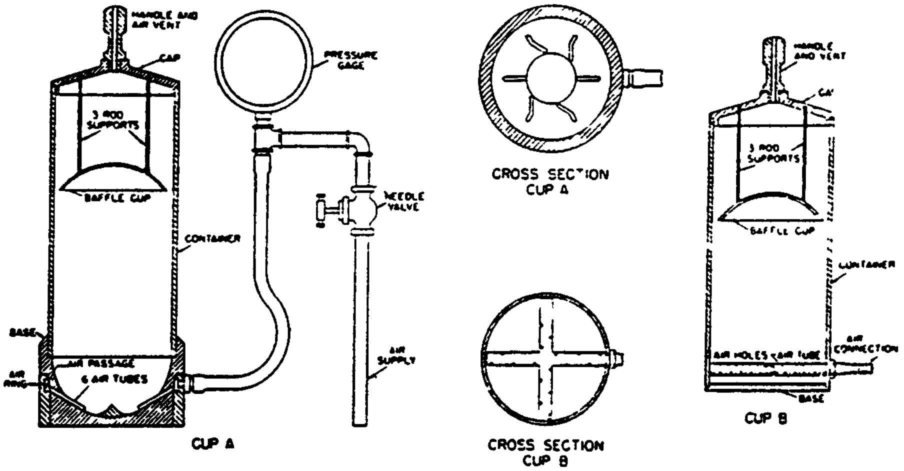


FIG. 3 Air-Jet Dispersion Cups of Apparatus B

5. Test Sample

5.1 Prepare the test sample for mechanical analysis as outlined in Practice D 421. During the preparation procedure the sample is divided into two portions. One portion contains only particles retained on the No. 10 (2.00-mm) sieve while the other portion contains only particles passing the No. 10 sieve. The mass of air-dried soil selected for purpose of tests, as prescribed in Practice D 421, shall be sufficient to yield quantities for mechanical analysis as follows:

5.1.1 The size of the portion retained on the No. 10 sieve shall depend on the maximum size of particle, according to the following schedule:

Nominal Diameter of Largest Particles, in. (mm)	Approximate Minimum Mass of Portion, g
3/8 (9.5)	500
3/4 (19.0)	1000
1 (25.4)	2000
1½ (38.1)	3000
2 (50.8)	4000
3 (76.2)	5000

5.1.2 The size of the portion passing the No. 10 sieve shall be approximately 115 g for sandy soils and approximately 65 g for silt and clay soils.

5.2 Provision is made in Section 5 of Practice D 421 for weighing of the air-dry soil selected for purpose of tests, the separation of the soil on the No. 10 sieve by dry-sieving and washing, and the weighing of the washed and dried fraction retained on the No. 10 sieve. From these two masses the percentages retained and passing the No. 10 sieve can be calculated in accordance with 12.1.

NOTE 8—A check on the mass values and the thoroughness of pulverization of the clods may be secured by weighing the portion passing the No. 10 sieve and adding this value to the mass of the washed and oven-dried portion retained on the No. 10 sieve.

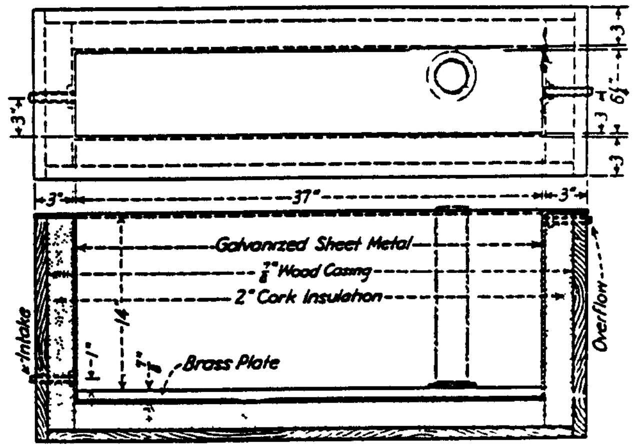
SIEVE ANALYSIS OF PORTION RETAINED ON NO. 10 (2.00-mm) SIEVE

6. Procedure

6.1 Separate the portion retained on the No. 10 (2.00-mm) sieve into a series of fractions using the 3-in. (75-mm), 2-in. (50-mm), 1½-in. (37.5-mm), 1-in. (25.0-mm), ¾-in. (19.0-mm), ⅜-in. (9.5-mm), No. 4 (4.75-mm), and No. 10 sieves, or as many as may be needed depending on the sample, or upon the specifications for the material under test.

6.2 Conduct the sieving operation by means of a lateral and vertical motion of the sieve, accompanied by a jarring action in order to keep the sample moving continuously over the surface of the sieve. In no case turn or manipulate fragments in the sample through the sieve by hand. Continue sieving until not more than 1 mass % of the residue on a sieve passes that sieve during 1 min of sieving. When mechanical sieving is used, test the thoroughness of sieving by using the hand method of sieving as described above.

6.3 Determine the mass of each fraction on a balance conforming to the requirements of 3.1. At the end of weighing, the sum of the masses retained on all the sieves used should equal closely the original mass of the quantity sieved.



Metric Equivalents

in.	⅞	1	3	6¼	14	37
mm	22.2	25.4	76.2	158.2	356	940

FIG. 4 Insulated Water Bath

HYDROMETER AND SIEVE ANALYSIS OF PORTION PASSING THE NO. 10 (2.00-mm) SIEVE

7. Determination of Composite Correction for Hydrometer Reading

7.1 Equations for percentages of soil remaining in suspension as given in 14.3 are based on the use of distilled or demineralized water. A dispersing agent is used in the water, however, and the specific gravity of the resulting liquid is appreciably greater than that of distilled or demineralized water.

7.1.1 Both soil hydrometers are calibrated at 68°F (20°C), and variations in temperature from this standard temperature produce inaccuracies in the actual hydrometer readings. The amount of the inaccuracy increases as the variation from the standard temperature increases.

7.1.2 Hydrometers are graduated by the manufacturer to be read at the bottom of the meniscus formed by the liquid on the stem. Since it is not possible to secure readings of soil suspensions at the bottom of the meniscus, readings must be taken at the top and a correction applied.

7.1.3 The net amount of the corrections for the three items enumerated is designated as the composite correction, and may be determined experimentally.

7.2 For convenience, a graph or table of composite corrections for a series of 1° temperature differences for the range of expected test temperatures may be prepared and used as needed. Measurement of the composite corrections may be made at two temperatures spanning the range of expected test temperatures, and corrections for the intermediate temperatures calculated assuming a straight-line relationship between the two observed values.

7.3 Prepare 1000 mL of liquid composed of distilled or demineralized water and dispersing agent in the same proportion as will prevail in the sedimentation (hydrometer) test. Place the liquid in a sedimentation cylinder and the cylinder in the constant-temperature water bath, set for one of the two temperatures to be used. When the temperature of the liquid becomes constant, insert the hydrometer, and, after a short interval to permit the hydrometer to come to the temperature of the liquid, read the hydrometer at the top of the meniscus formed on the stem. For hydrometer 151H the composite correction is the difference between this reading and one; for hydrometer 152H it is the difference between the reading and zero. Bring the liquid and the hydrometer to the other temperature to be used, and secure the composite correction as before.

8. Hygroscopic Moisture

8.1 When the sample is weighed for the hydrometer test, weigh out an auxiliary portion of from 10 to 15 g in a small metal or glass container, dry the sample to a constant mass in an oven at 230 ± 9°F (110 ± 5°C), and weigh again. Record the masses.

9. Dispersion of Soil Sample

9.1 When the soil is mostly of the clay and silt sizes, weigh out a sample of air-dry soil of approximately 50 g. When the soil is mostly sand the sample should be approximately 100 g.

9.2 Place the sample in the 250-mL beaker and cover with 125 mL of sodium hexametaphosphate solution (40 g/L). Stir until the soil is thoroughly wetted. Allow to soak for at least 16 h.

9.3 At the end of the soaking period, disperse the sample further, using either stirring apparatus A or B. If stirring apparatus A is used, transfer the soil - water slurry from the beaker into the special dispersion cup shown in Fig. 2, washing any residue from the beaker into the cup with distilled or demineralized water (Note 9). Add distilled or demineralized water, if necessary, so that the cup is more than half full. Stir for a period of 1 min.

NOTE 9—A large size syringe is a convenient device for handling the water in the washing operation. Other devices include the wash-water bottle and a hose with nozzle connected to a pressurized distilled water tank.

9.4 If stirring apparatus B (Fig. 3) is used, remove the cover cap and connect the cup to a compressed air supply by means of a rubber hose. A air gage must be on the line between the cup and the control valve. Open the control valve so that the gage indicates 1 psi (7 kPa) pressure (Note 10). Transfer the soil - water slurry from the beaker to the air-jet dispersion cup by washing with distilled or demineralized water. Add distilled or demineralized water, if necessary, so that the total volume in the cup is 250 mL, but no more.

NOTE 10—The initial air pressure of 1 psi is required to prevent the soil - water mixture from entering the air-jet chamber when the mixture is transferred to the dispersion cup.

9.5 Place the cover cap on the cup and open the air control valve until the gage pressure is 20 psi (140 kPa). Disperse the soil according to the following schedule:

Plasticity Index	Dispersion Period, min
Under 5	5
6 to 20	10
Over 20	15

Soils containing large percentages of mica need be dispersed for only 1 min. After the dispersion period, reduce the gage pressure to 1 psi preparatory to transfer of soil - water slurry to the sedimentation cylinder.

10. Hydrometer Test

10.1 Immediately after dispersion, transfer the soil - water slurry to the glass sedimentation cylinder, and add distilled or demineralized water until the total volume is 1000 mL.

10.2 Using the palm of the hand over the open end of the cylinder (or a rubber stopper in the open end), turn the cylinder upside down and back for a period of 1 min to complete the agitation of the slurry (Note 11). At the end of 1 min set the cylinder in a convenient location and take hydrometer readings at the following intervals of time (measured from the beginning of sedimentation), or as many as may be needed, depending on the sample or the specification for the material under test: 2, 5, 15, 30, 60, 250, and 1440 min. If the controlled water bath is used, the sedimentation cylinder should be placed in the bath between the 2- and 5-min readings.

NOTE 11—The number of turns during this minute should be approximately 60, counting the turn upside down and back as two turns.

Any soil remaining in the bottom of the cylinder during the first few turns should be loosened by vigorous shaking of the cylinder while it is in the inverted position

10.3 When it is desired to take a hydrometer reading, carefully insert the hydrometer about 20 to 25 s before the reading is due to approximately the depth it will have when the reading is taken. As soon as the reading is taken, carefully remove the hydrometer and place it with a spinning motion in a graduate of clean distilled or demineralized water.

NOTE 12—It is important to remove the hydrometer immediately after each reading. Readings shall be taken at the top of the meniscus formed by the suspension around the stem, since it is not possible to secure readings at the bottom of the meniscus.

10.4 After each reading, take the temperature of the suspension by inserting the thermometer into the suspension.

11. Sieve Analysis

11.1 After taking the final hydrometer reading, transfer the suspension to a No. 200 (75-µm) sieve and wash with tap water until the wash water is clear. Transfer the material on the No. 200 sieve to a suitable container, dry in an oven at 230 ± 9°F (110 ± 5°C) and make a sieve analysis of the portion retained, using as many sieves as desired, or required for the material, or upon the specification of the material under test.

CALCULATIONS AND REPORT

12. Sieve Analysis Values for the Portion Coarser than the No. 10 (2.00-mm) Sieve

12.1 Calculate the percentage passing the No. 10 sieve by dividing the mass passing the No. 10 sieve by the mass of soil originally split on the No. 10 sieve, and multiplying the result by 100. To obtain the mass passing the No. 10 sieve, subtract the mass retained on the No. 10 sieve from the original mass.

12.2 To secure the total mass of soil passing the No. 4 (4.75-mm) sieve, add to the mass of the material passing the No. 10 sieve the mass of the fraction passing the No. 4 sieve and retained on the No. 10 sieve. To secure the total mass of soil passing the ⅜-in. (9.5-mm) sieve, add to the total mass of soil passing the No. 4 sieve, the mass of the fraction passing the ⅜-in. sieve and retained on the No. 4 sieve. For the remaining sieves, continue the calculations in the same manner.

12.3 To determine the total percentage passing for each sieve, divide the total mass passing (see 12.2) by the total mass of sample and multiply the result by 100.

13. Hygroscopic Moisture Correction Factor

13.1 The hydroscopic moisture correction factor is the ratio between the mass of the oven-dried sample and the air-dry mass before drying. It is a number less than one, except when there is no hygroscopic moisture.

14. Percentages of Soil in Suspension

14.1 Calculate the oven-dry mass of soil used in the hydrometer analysis by multiplying the air-dry mass by the hygroscopic moisture correction factor.

TABLE 1 Values of Correction Factor a for Different Specific Gravities of Soil Particles[A]

Specific Gravity	Correction Factor[A]
2.95	0.94
2.90	0.95
2.85	0.96
2.80	0.97
2.75	0.98
2.70	0.99
2.65	1.00
2.60	1.01
2.55	1.02
2.50	1.03
2.45	1.05

[A] For use in equation for percentage of soil remaining in suspension when using Hydrometer 152H.

14.2 Calculate the mass of a total sample represented by the mass of soil used in the hydrometer test, by dividing the oven-dry mass used by the percentage passing the No. 10 (2.00-mm) sieve, and multiplying the result by 100. This value is the weight W in the equation for percentage remaining in suspension.

14.3 The percentage of soil remaining in suspension at the level at which the hydrometer is measuring the density of the suspension may be calculated as follows (Note 13). For hydrometer 151H:

$$P = [(100\,000/W) \times G/(G - G_1)](R - G_1)$$

NOTE 13—The bracketed portion of the equation for hydrometer 151H is constant for a series of readings and may be calculated first and then multiplied by the portion in the parentheses.

For hydrometer 152H

$$P = (Ra/W) \times 100$$

where

a = correction faction to be applied to the reading of hydrometer 152H. (Values shown on the scale are computed using a specific gravity of 2.65. Correction factors are given in Table 1),

P = percentage of soil remaining in suspension at the level at which the hydrometer measures the density of the suspension,

R = hydrometer reading with composite correction applied (Section 7),

W = oven-dry mass of soil in a total test sample represented by mass of soil dispersed (see 14.2), g,

G = specific gravity of the soil particles, and

G_1 = specific gravity of the liquid in which soil particles are suspended. Use numerical value of one in both instances in the equation. In the first instance any possible variation produces no significant effect, and in the second instance, the composite correction for R is based on a value of one for G_1.

15. Diameter of Soil Particles

15.1 The diameter of a particle corresponding to the percentage indicated by a given hydrometer reading shall be calculated according to Stokes' law (Note 14), on the basis that a particle of this diameter was at the surface of the suspension at the beginning of sedimentation and had settled to the level at which the hydrometer is measuring the density of the suspension. According to Stokes' law:

$$D = \sqrt{[30n/980(G - G_1)] \times L/T}$$

Charac[illegible]

Major Divisions (1)	(2)	Symbol Letter (3)	Symbol Hatching (4)	Symbol Color (5)	Name (6)	Value as Subgrade When Not Subject to Frost Action (7)	Value as [illegible] When Not S[illegible] to Frost A[illegible] (8)
COARSE-GRAINED SOILS	GRAVEL AND GRAVELLY SOILS	GW		Red	Well-graded gravels or gravel-sand mixtures, little or no fines	Excellent	Excellent
		GP		Red	Poorly graded gravels or gravel-sand mixtures, little or no fines	Good to excellent	Good
		GM d		Yellow	Silty gravels, gravel-sand-silt mixtures	Good to excellent	Good
		GM u		Yellow		Good	Fair
		GC		Yellow	Clayey gravels, gravel-sand-clay mixtures	Good	Fair
	SAND AND SANDY SOILS	SW		Red	Well-graded sands or gravelly sands, little or no fines	Good	Fair to go[illegible]
		SP		Red	Poorly graded sands or gravelly sands little or no fines	Fair to good	Fair
		SM d		Yellow	Silty sands, sand-silt mixtures	Fair to good	Fair to goo[illegible]
		SM u		Yellow		Fair	Poor to fa[illegible]
		SC		Yellow	Clayey sands, sand-clay mixtures	Poor to fair	Poor
FINE-GRAINED SOILS	SILTS AND CLAYS LL IS LESS THAN 50	ML		Green	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity	Poor to fair	Not suitab[illegible]
		CL		Green	Inorganic clays of low to medium plasticity gravelly clays, sandy clays, silty clays lean clays	Poor to fair	Not suitab[illegible]
		OL		Green	Organic silts and organic silt-clays of low plasticity	Poor	Not suitab[illegible]
	SILTS AND CLAYS LL IS GREATER THAN 50	MH		Blue	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts	Poor	Not suitab[illegible]
		CH		Blue	Inorganic clays of high plasticity, fat clays	Poor to fair	Not suitab[illegible]
		OH		Blue	Organic clays of medium to high plasticity, organic silts	Poor to very poor	Not suitab[illegible]
HIGHLY ORGANIC SOILS		Pt		Orange	Peat and other highly organic soils	Not suitable	Not suitab[illegible]

Note

1 Column [illegible], division of GM and SM groups into subdivisions of d and u are for roads and airfields only Subdivision is on b[illegible] plasticity index is 5 or less the suffix u will be used otherwise

2 In column [illegible]3, the equipment listed will usually produce the required densities with a reasonable number of passes when moisture con[illegible] are listed because variable soil characteristics within a given soil group may require different equipment In some instances a co[illegible]

a <u>Processed base materials and other angular materials</u> Steel-wheeled and rubber-tired rollers are recommended for hard angular m[illegible] subject to degradation

b <u>Finishing</u> Rubber-tired equipment is recommended for rolling during final shaping operations for most soils and processed mate[illegible]

c <u>Equipment size</u> The following sizes of equipment are necessary to assure the high densities required for airfield construc[illegible]

Crawler-type tractor -- total weight in excess of 30 000 lb

Rubber-tired equipment -- wheel load in excess of 15,000 lb, wheel loads as high as 40,000 lb may be necessary to obtain the re[illegible]

Sheepsfoot roller -- unit pressure (on 6- to 12-sq-in foot) to be in excess of 250 psi and unit pressures as high as 650 ps[illegible] be at least 5 per cent of the total peripheral area of the drum using the diameter measured to the faces of the feet

3 Column 14 unit dry weight are for compacted [illegible] at optimum moisture content for modified AASHO compaction effort (CE 55)

4 In column [illegible]5 the maximum value that can be used in design of airfields is, in some cases limited by gradation and plasticity re[illegible]

Table 1

Characteristics Pertinent to Roads and Airfields

	Value as Subgrade When Not Subject to Frost Action (7)	Value as Subbase When Not Subject to Frost Action (8)	Value as Base When Not Subject to Frost Action (9)	Potential Frost Action (10)	Compressibility and Expansion (11)	Drainage Characteristics (12)	
and	Excellent	Excellent	Good	None to very slight	Almost none	Excellent	Crav ro ler
, sand	Good to excellent	Good	Fair to good	None to very slight	Almost none	Excellent	Crawle rolle
mixtures	Good to excellent	Good	Fair to good	Slight to medium	Very slight	Fair to poor	Rubbe rolle
	Good	Fair	Poor to not suitable	Slight to medium	Slight	Poor to practically impervious	Rubbe rolle
y mixtures	Good	Fair	Poor to not suitable	Slight to medium	Slight	Poor to practically impervious	Rubber rolle
ands,	Good	Fair to good	Poor	None to very slight	Almost none	Excellent	Crawle rolle
	Fair to good	Fair	Poor to not suitable	None to very slight	Almost none	Excellent	Crawle rolle
	Fair to good	Fair to good	Poor	Slight to high	Very slight	Fair to poor	Rubbe rolle moistu
,	Fair	Poor to fair	Not suitable	Slight to high	Slight to medium	Poor to practically impervious	Rubbe rolle
s	Poor to fair	Poor	Not suitable	Slight to high	Slight to medium	Poor to practically impervious	Rubber roller
ands, rock ds or ity	Poor to fair	Not suitable	Not suitable	Medium to very high	Slight to medium	Fair to poor	Rubbe rolle
m plastic- s, silty	Poor to fair	Not suitable	Not suitable	Medium to high	Medium	Practically impervious	Rubber rolle
clays of	Poor	Not suitable	Not suitable	Medium to high	Medium to high	Poor	Rubber roller
diatomaceous tic silts	Poor	Not suitable	Not suitable	Medium to very high	High	Fair to poor	Sheeps roller
ity fat	Poor to fair	Not suitable	Not suitable	Medium	High	Practically impervious	Sheepr roller
s	Poor to very poor	Not suitable	Not suitable	Medium	High	Practically impervious	Sheeps roller
soils	Not suitable	Not suitable	Not suitable	Slight	Very high	Fair to poor	Compac

ard airfields only Subdivision is on basis of Atterberg limits suffix d (e g , GMd) will be used when the liquid limit . 25 or le.. and th

reasonable number of passes when moisture conditions and thickness of lift are properly controlled In some instances several types of equip different equipment In some instances, a combination of two types may be necessary
red rollers are recommended for hard, angular materials with limited fines or screenings Rubber-tired equipment is recommended for softer mat

operations for most soils and processed materials
densities required for airfield construction

as 40,000 lb may be necessary to obtain the required densities for some materials (based on contact pressure of approximately 65 to 150 ps)
250 psi and unit pressures as high as 650 psi may be necessary to obtain the required densities for some materials The area of the fee shoul
meter measured to the faces of the feet
ified AASHO compaction effort (CE 55)
ses limited by gradation and plasticity requirements

B-8-B

i Airfields

Potential Frost Action (10)	Compressibility and Expansion (11)	Drainage Characteristics (12)	Compaction Equipment (13)	Unit Dry Weight lb per cu ft (14)	Typical Design Values CBR (15)	Subgrade Modulus k lb per cu in (16)
None to very slight	Almost none	Excellent	Crawler type tractor rubber tired roller steel-wheeled roller	125-140	40-80	300-500
None to very slight	Almost none	Excellent	Crawler type tractor rubber-tired roller steel-wheeled roller	110-140	30-60	300-500
Slight to medium	Very slight	Fair to poor	Rubber tired roller sheepsfoot roller close control of moisture	125-145	40-60	300-500
Slight to medium	Slight	Poor to practically impervious	Rubber-tired roller, sheepsfoot roller	115-135	20-30	200-500
Slight to medium	Slight	Poor to practically impervious	Rubber tired roller, sheepsfoot roller	130-145	20-40	200-500
None to very slight	Almost none	Excellent	Crawler-type tractor, rubber-tired roller	110-130	20-40	200-400
None to very slight	Almost none	Excellent	Crawler-type tractor, rubber-tired roller	105-135	10-40	150-400
Slight to high	Very slight	Fair to poor	Rubber tired roller sheepsfoot roller close control of moisture	120-135	15-40	150-400
Slight to high	Slight to medium	Poor to practically impervious	Rubber-tired roller, sheepsfoot roller	100-130	10-20	100-300
Slight to high	Slight to medium	Poor to practically impervious	Rubber tired roller, sheepsfoot roller	100-135	5-20	100-300
Medium to very high	Slight to medium	Fair to poor	Rubber tired roller, sheepsfoot roller close control of moisture	90-130	15 or less	100-200
Medium to high	Medium	Practically impervious	Rubber-tired roller sheepsfoot roller	90-130	15 or less	50-150
Medium to high	Medium to high	Poor	Rubber tired roller, sheepsfoot roller	90-105	5 or less	50-100
Medium to very high	High	Fair to poor	Sheepsfoot roller, rubber-tired roller	80-105	10 or less	50-100
Medium	High	Practically impervious	Sheepsfoot roller, rubber-tired roller	90-115	15 or less	50-150
Medium	High	Practically impervious	Sheepsfoot roller, rubber-tired roller	80-110	5 or less	25-100
Slight	Very high	Fair to poor	Compaction not practical	-	-	-

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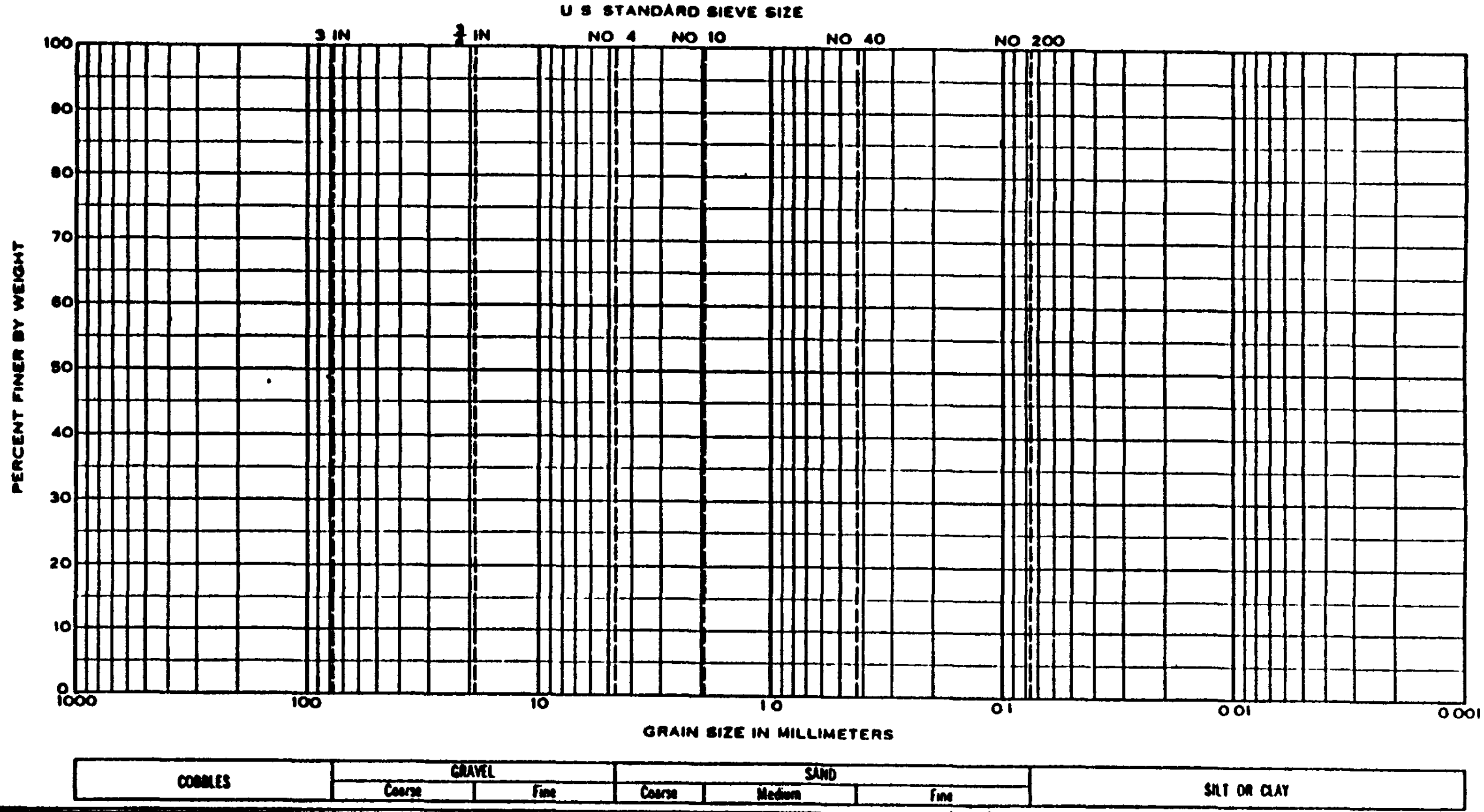
(e g , GMd) will be used when the liquid limit is 25 or less and the

re properly controlled In some instances, several types of equipment necessary

r screenings Rubber-tired equipment is recommended for some materials

erials (based on contact pressure of approximately 65 to 150 psi) required densities for some materials The area of the feet should

6-8-C



Sample No	Elev or Depth	Classification	Nat WC	LL	PL	PI	

Project

Area

Boring No

Date

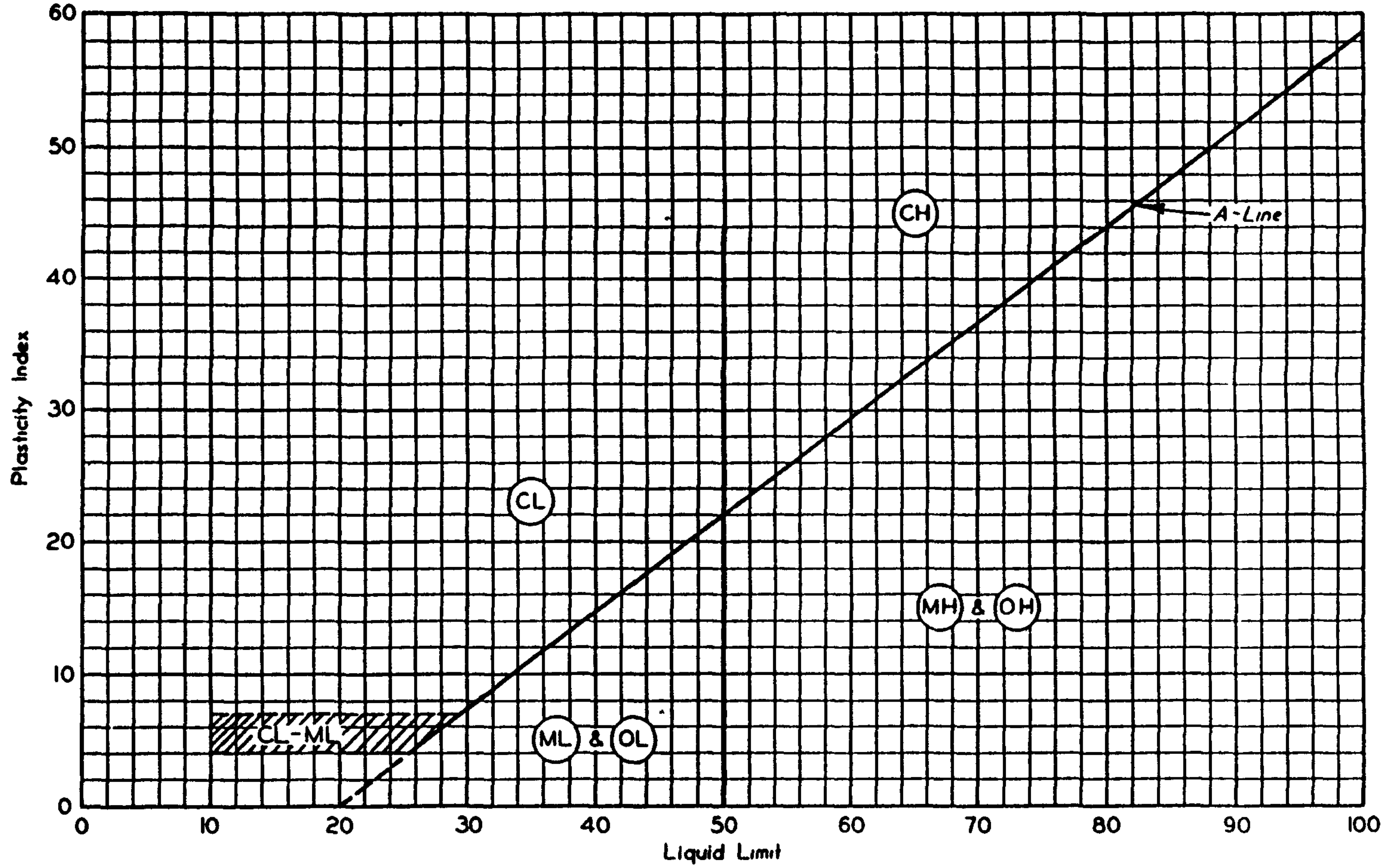
062552 C

GRADATION CURVES

PLATE 1

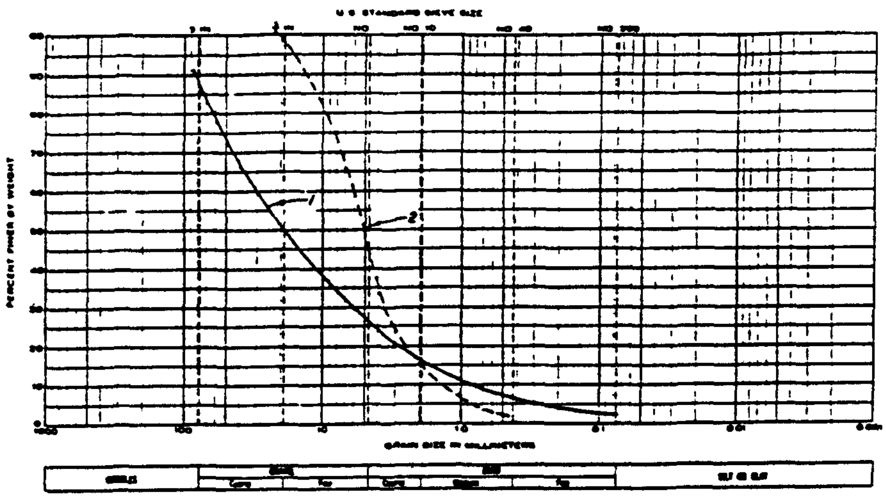
PLATE 2

34



PLASTICITY CHART

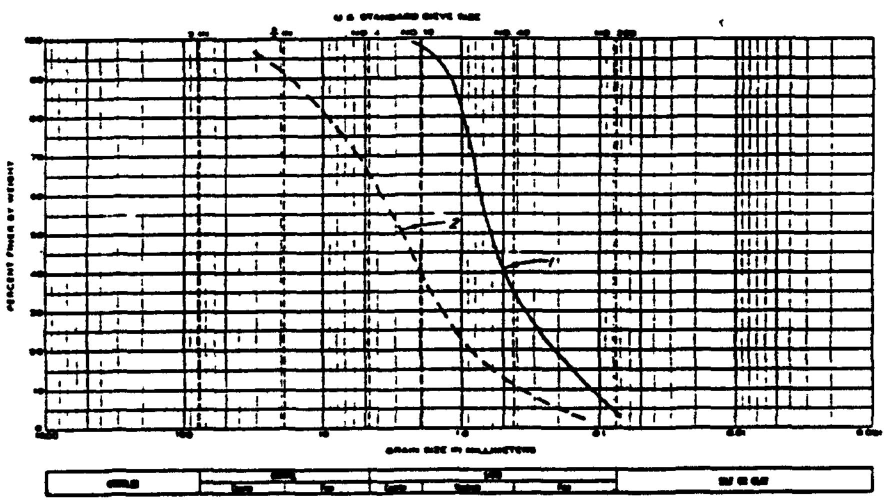
R-011953-C



CURVE 1 Pit run gravel nonplastic well-graded small percentage of fines
CURVE 2 Sandy gravel; nonplastic, no fines Curve is about the steepest one that will meet the criteria for GW group

G W GROUP

FIG 1



CURVE 1 Medium to fine sand, nonplastic, well-graded Curve is about the steepest one that will meet the criteria for SW group
CURVE 2 Gravelly sand; nonplastic well-graded

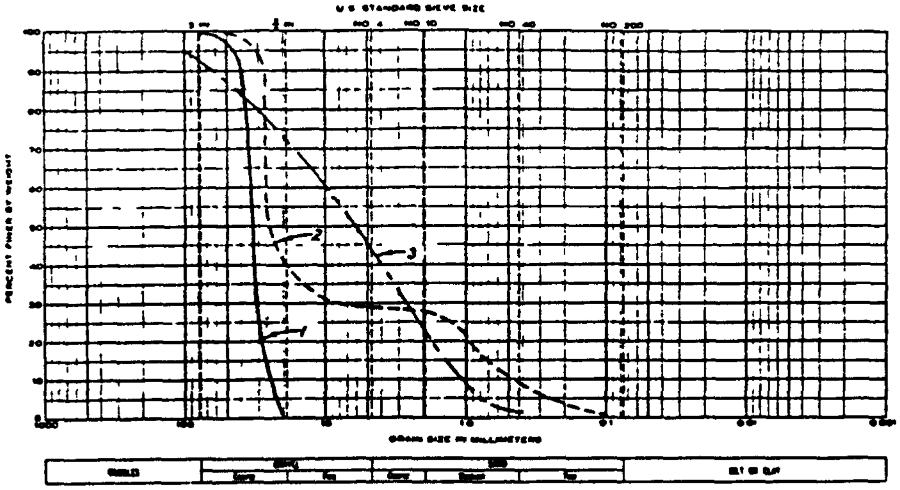
SW GROUP

FIG 2

TYPICAL EXAMPLES
GW AND SW SOILS

062652-A

PLATE 3



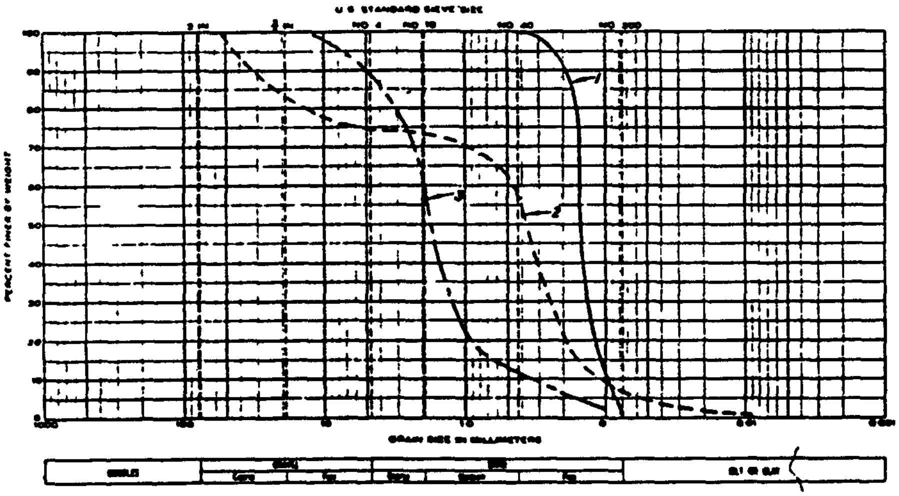
CURVE 1 Uniform coarse gravel, nonplastic. Very uniform gradation

CURVE 2 Gravel sand mixture, nonplastic. Gravel is almost all of one size (3/4- to 1-in.), no fine gravel present. Poorly graded

CURVE 3 Sandy gravel, nonplastic. All sizes are present, but gradation does not meet curvature criterion for GW

GP GROUP

FIG 1



CURVE 1 Uniform fine sand, nonplastic

CURVE 2 Poorly graded gravelly sand mixture; nonplastic. Approximately 7 per cent fines makes this a borderline soil, symbol SP-SM

CURVE 3 Coarse to medium sand, nonplastic. Approaching uniform gradation, does not meet curvature criterion for SW

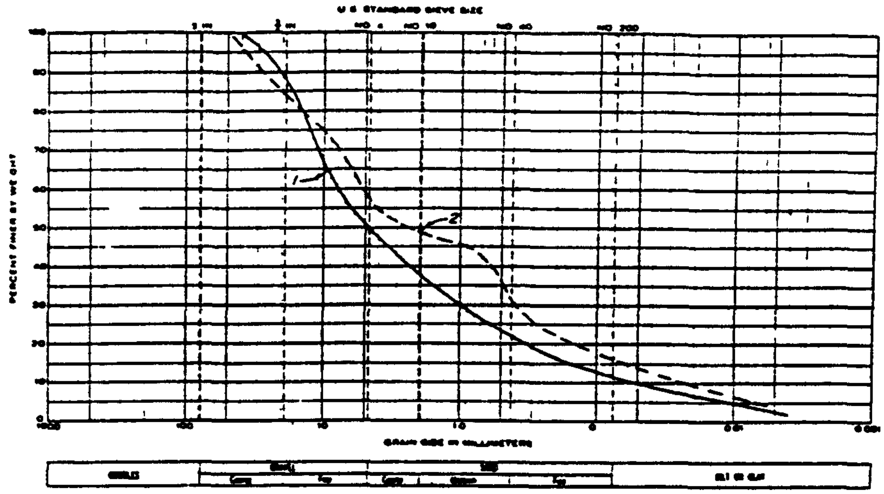
SP GROUP

FIG 2

TYPICAL EXAMPLES
GP AND SP SOILS

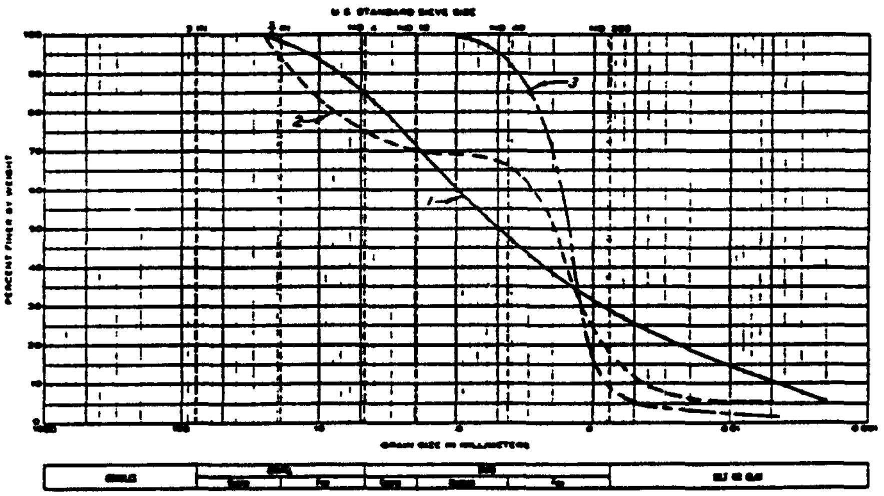
062852-B

PLATE 4



CURVE Crushed limestone ... 16 PI-2 Well-graded Made excellent base course material
CURVE 2 Gravel-sand-silt mixture LL-32 PI-6 Poorly graded

GM GROUP
FIG 1

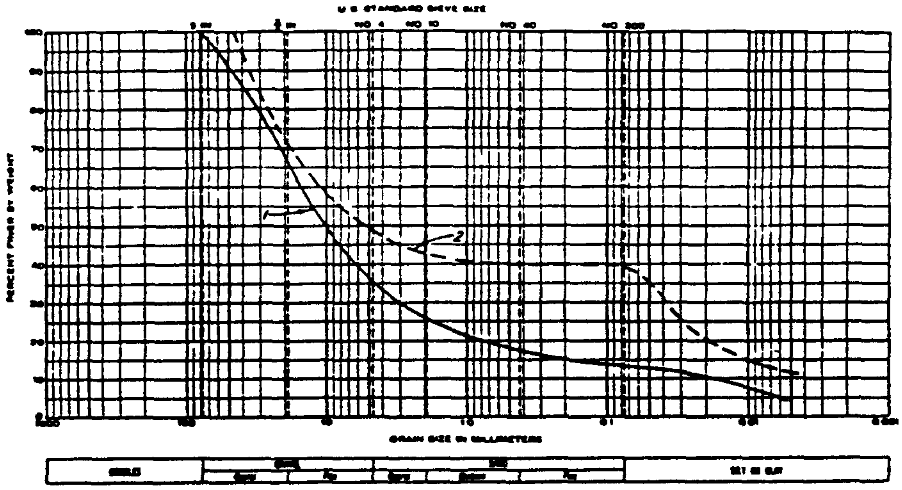


CURVE 1 Silty gravelly sand, nonplastic Micaceous silt stabilized with sandy chert gravel
CURVE 2 Mixture of gravel-sand and fine silty sand nonplastic Poorly graded mixture; note absence of coarse and medium sand
CURVE 3 Silty fine sand, LL-22, PI-5 Uniform gradation, amount passing No 200 sieve, and Atterberg limits classify soil as borderline in SP-SM-SC groups Classify as SP-SM.

SM GROUP
FIG 2

TYPICAL EXAMPLES
GM AND SM SOILS

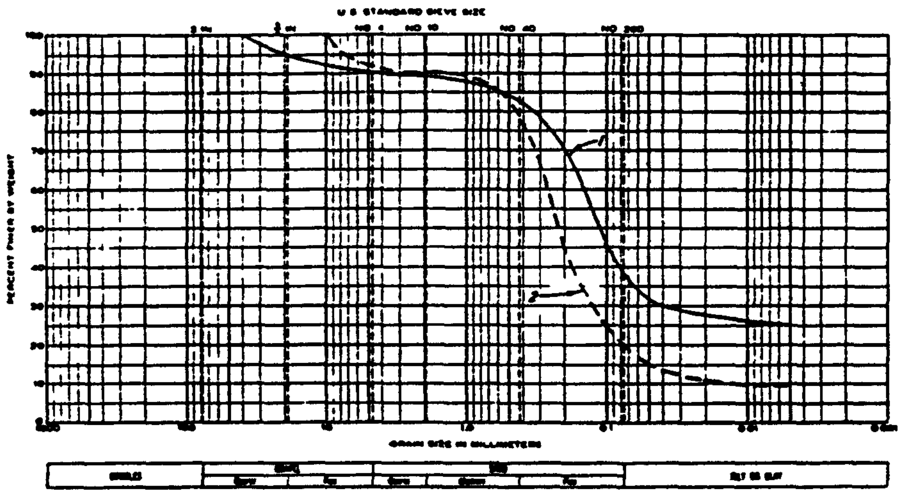
062652-C



CURVE 1: Clay-gravel (chert), LL-40, PI-19 Fairly low percentage of plastic fines
CURVE 2 Natural mixture of gravel and clay, LL-46, PI-20 Very poorly graded; almost no sand sizes present

GC GROUP

FIG 1



CURVE 1 Clayey sand; LL-23, PI-10 Poorly graded mixture of sand-clay and fine silty sand
CURVE 2: Limerock and sand mixture, LL-23, PI-8 Poorly graded.

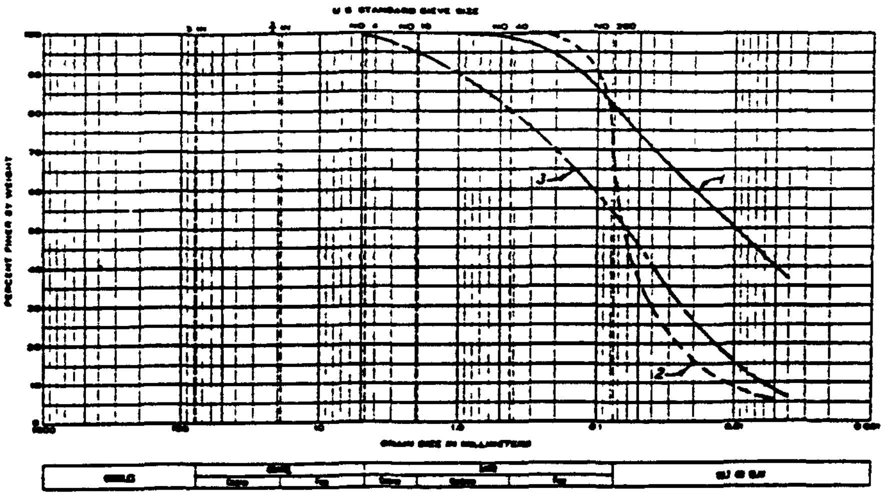
SC GROUP

FIG 2

TYPICAL EXAMPLES
GC AND SC SOILS

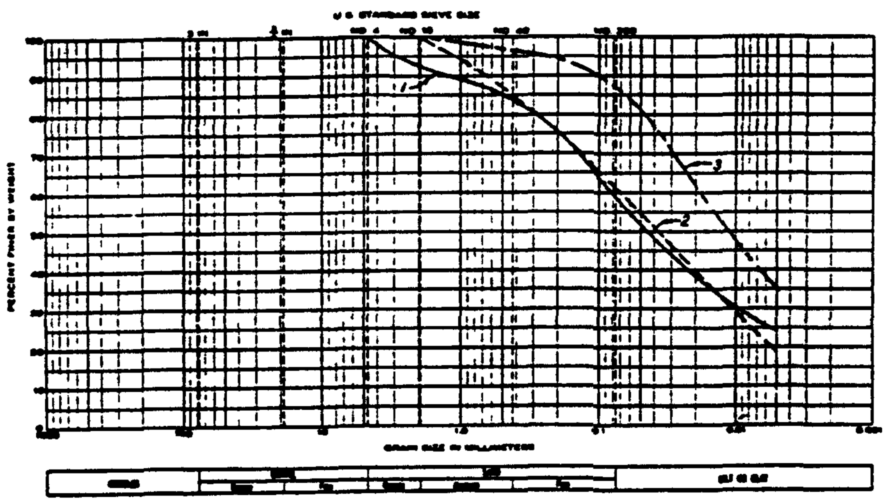
062652-D

PLATE 6



CURVE 1 Clayey silt, LL-46 PI-16
CURVE 2 Uniform sandy silt, LL-30 PI-3
CURVE 3 Sandy silt, LL-34 PI-3
GENERAL. Note curves 2 and 3 have about the same plasticity but vary in grain size distribution

ML GROUP
FIG 1



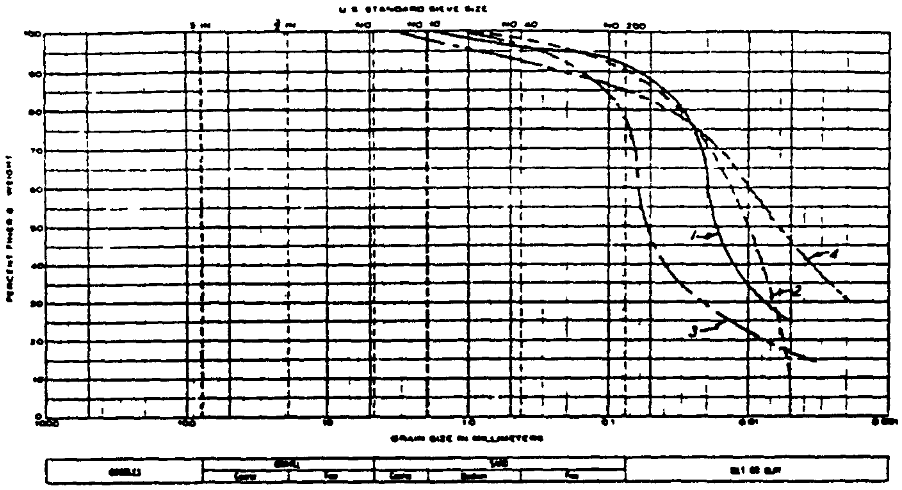
CURVE 1 Micaceous sandy silt, LL-55, PI-6
CURVE 2 Sandy silt; LL-67, PI-27
CURVE 3 Clayey silt; LL-54 PI-24
GENERAL. Note curves 1 and 2 have approximately the same grain size but are widely different in plasticity

MH GROUP
FIG 2

TYPICAL EXAMPLES
ML AND MH SOILS

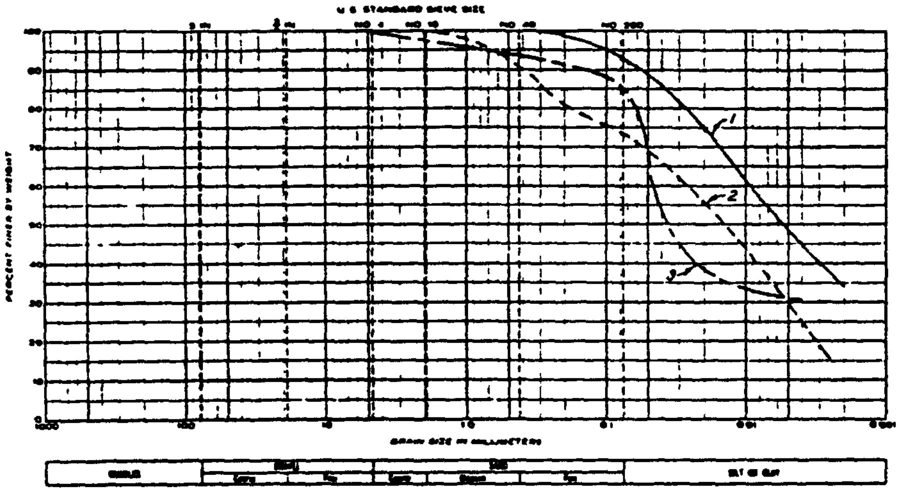
062652-C

PLATE 7



CURVE 1 Lean c ay LL-30, PI-13
CURVE 2 Silty clay, LL-25, PI-6 Borderline, classify as CL-ML
CURVE 3 Sandy clay, LL-31, PI-18
CURVE 4 Clay LL-44, PI-25

CL GROUP
FIG 1



CURVE 1 Silt, clay, LL 52 PI-25
CURVE 2 Sandy fat clay LL-75 PI-45
CURVE 3 Sandy clay, LL-51 PI-29

CH GROUP
FIG 2

TYPICAL EXAMPLES
CL AND CH SOILS

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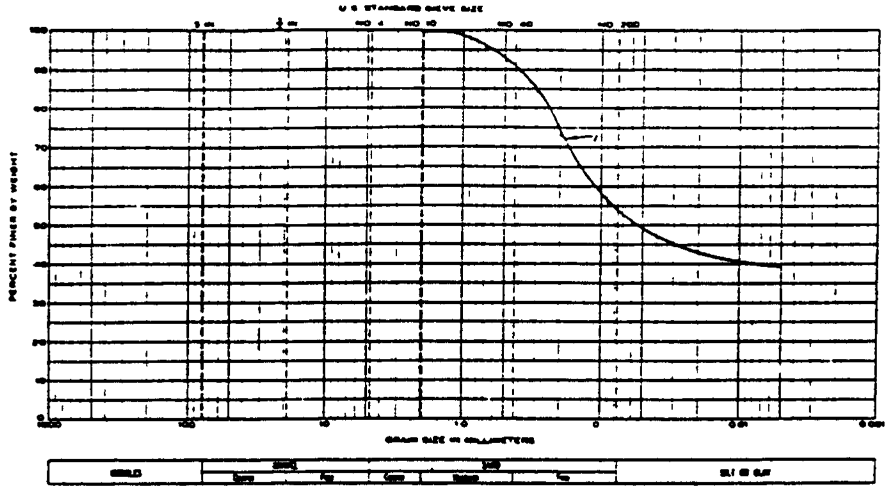
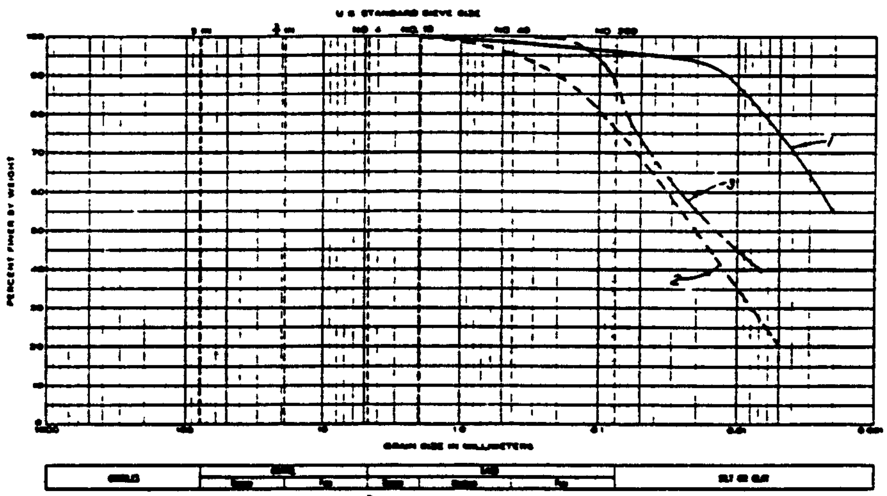
PLATE 8



CURVE 1 Organic sandy clay LL-46 PI 15

OL GROUP

FIG 1



CURVE 1 Organic clay (tidal flats) LL-95, PI-39
CURVE 2 Alkali clay with organic matter LL-66, PI-27
CURVE 3 Organic silt, LL-70, PI-33 (natural water content), LL-53, PI-19 (oven dried)

OH GROUP

FIG 2

TYPICAL EXAMPLES
OL AND OH SOILS

062852-C

PLATE 9

AD/A026 473

THE UNIFIED SOIL CLASSIFICATION SYSTEM - APPENDIX A: CHARACTERISTICS OF SOIL GROUPS PERTAINING TO EMBANKMENTS AND FOUNDATIONS - APPENDIX B· CHARACTERISTICS OF SOIL GROUPS PERTAINING TO ROADS AND AIRFIELDS

(U.S.) Army Engineer Waterways Experiment Station
Vicksburg, MS

Apr 60

AD/A026 473

TECHNICAL MEMORANDUM NO 3-357

THE UNIFIED SOIL CLASSIFICATION SYSTEM

APPENDIX A

CHARACTERISTICS OF SOIL GROUPS PERTAINING TO EMBANKMENTS AND FOUNDATIONS

APPENDIX B

CHARACTERISTICS OF SOIL GROUPS PERTAINING TO ROADS AND AIRFIELDS

April 1960
(Reprinted May 1967)

Sponsored by

Office, Chief of Engineers
U. S. Army

Conducted by

U. S. Army Engineer Waterways Experiment Station
CORPS OF ENGINEERS
Vicksburg, Mississippi

ARMY MRC VICKSBURG MISS

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TECHNICAL MEMORANDUM NO. 3-357

APPENDIX A
CHARACTERISTICS OF SOIL GROUPS PERTAINING TO EMBANKMENTS AND FOUNDATIONS

March 1953

Sponsored by

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U. S. Army

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U. S. Army Engineer Waterways Experiment Station
CORPS OF ENGINEERS
Vicksburg, Mississippi

A-i

Contents

Preface

The purpose of this manual is to describe and explain the use of the "Unified Soil Classification System" in order that identification of soil types will be on a common basis throughout the agencies using this system.

The program of military airfield construction undertaken by the Department of the Army in 1941 revealed at an early stage that existing soil classifications were not entirely applicable to the work involved. In 1942 the Corps of Engineers tentatively adopted the "Airfield Classification" of soils which had been developed by Dr. Arthur Casagrande of the Harvard University Graduate School of Engineering. As a result of experience gained since that time, the original classification has been expanded and revised in cooperation with the Bureau of Reclamation so that it applies not only to airfields but also to embankments, foundations, and other engineering features.

Acknowledgment is made to Dr. Arthur Casagrande, Professor of Soil Mechanics and Foundation Engineering, Harvard University, for permission to incorporate in this manual considerable information from the paper "Classification and Identification of Soils" published in Transactions, American Society of Civil Engineers, volume 113, 1948. This manual was prepared under the direction of the Office, Chief of Engineers, by the Soils Division, Waterways Experiment Station.

Contents

UNIFIED SOIL CLASSIFICATION SYSTEM

Introduction

Need for a classification system

1. The adoption of the principles of soil mechanics by the engineering profession has inspired numerous attempts to devise a simple classification system that will tell the engineer the properties of a given soil. As a consequence, many classifications have come into existence based on certain properties of soils such as texture, plasticity, strength, and other characteristics. A few classification systems have gained fairly wide acceptance, but it is seldom that any particular system has provided the complete information on a soil that the engineer needs. Nearly every engineer who practices soil mechanics will add judgment and personal experience as modifiers to whatever soil classification system he uses, so that it may be said that there are as many classification systems as there are engineers using them. Obviously, within a given agency, where designs and plans are reviewed by persons entirely removed from a project, a common basis of soil classification is necessary so that when an engineer classifies a soil as a certain type, this classification will convey to another engineer not familiar with the region the proper characteristics and behavior of the material. Further than this, the classification should reflect those behavior characteristics of the soil that are pertinent to the project under consideration.

Basis of the unified soil classification system

2. The unified soil classification system is based on the

identification of soils according to their textural and plasticity qualities and on their grouping with respect to behavior. Soils seldom exist in nature separately as sand, gravel, or any other single component, but are usually found as mixtures with varying proportions of particles of different sizes; each component part contributes its characteristics to the soil mixture. The unified soil classification system is based on those characteristics of the soil that indicate how it will behave as an engineering construction material. The following properties have been found most useful for this purpose and form the basis of soil identification. They can be determined by simple tests and with experience can be estimated with some accuracy.

- a. Percentages of gravel, sand, and fines (fraction passing No. 200 sieve).
- b. Shape of the grain-size-distribution curve.
- c. Plasticity and compressibility characteristics.

In the unified soil classification system the soil is given a descriptive name and a letter symbol indicating its principal characteristics.

Purpose and scope of manual

3. It is the purpose of this manual to describe the various soil groups in detail and to discuss the methods of identification in order that a uniform classification procedure may be followed by all who use the system. Placement of the soils into their respective groups is accomplished by visual examination and laboratory tests as a means of basic identification. This procedure is described in the main text of this manual. The classification of the soils in these groups according to their engineering behavior for various types of construction, such as

embankments, foundations, roads, and airfields, is treated separately in appendices hereto which will be issued as the need arises. It is recognized that the unified classification system in its present form may not prove entirely adequate in all cases. However, it is intended that the classification of soils in accordance with this system have some degree of elasticity, and that the system not be followed blindly nor regarded as completely rigid.

Definitions of soil components

4. Before soils can be classified properly in any system, including the one presented in this manual, it is necessary to establish a basic terminology for the various soil components and to define the terms used. In the unified soil classification the names "cobbles," "gravel," "sand," and "fines (silt or clay)" are used to designate the size ranges of soil particles. The gravel and sand ranges are further subdivided into the groups presented below. The limiting boundaries between the various size ranges have been arbitrarily set at certain U. S. Standard sieve sizes in accordance with the following tabulation:

Component	Size Range
Cobbles	Above 3 in.
Gravel	3 in. to No. 4 (4.76 mm)
Coarse gravel	3 in. to 3/4 in.
Fine gravel	3/4 in. to No. 4 (4.76 mm)
Sand	No. 4 (4.76 mm) to No. 200 (0.074 mm)
Coarse sand	No. 4 (4.76 mm) to No. 10 (2.0 mm)
Medium sand	No. 10 (2.0 mm) to No. 40 (0.42 mm)
Fine sand	No. 40 (0.42 mm) to No. 200 (0.074 mm)
Fines (silt or clay)	Below No. 200 (0.074 mm)

These ranges are shown graphically on the grain-size sheet, plate 1. In the finest soil component (below No. 200 sieve) the terms "silt" and "clay" are used respectively to distinguish materials exhibiting lower plasticity from those with higher plasticity. The minus No. 200 sieve material is "silt" if the liquid limit and plasticity index plot below the "A" line on the plasticity chart (plate 2), and is "clay" if the liquid limit and plasticity index plot above the "A" line on the chart (all Atterberg limits tests based on minus No. 40 sieve fraction of a soil). The foregoing definition holds for inorganic silts and clays and for organic silts, but is not valid for organic clays since these latter soils plot below the "A" line. The names of the basic soil components can be used as nouns or adjectives in the name of a soil, as explained later.

The Classification System

5. A short discussion of the unified soil classification sheet, table 1, is presented in order that the succeeding detailed description may be more easily understood. This sheet is designed to apply generally to the identification of soils regardless of the intended engineering uses. The first three columns of the classification sheet show the major divisions of the classification and the group symbols that distinguish the individual soil types. Names of typical and representative soil types found in each group are shown in column 4. The field procedures for identifying soils by general characteristics and from pertinent tests and visual observations are shown in column 5. The desired descriptive information for a complete identification of a soil is presented in column 6. In column 7 are presented the laboratory

classification criteria by which the various soil groups are identified and distinguished. Table 2 shows an auxiliary schematic method of classifying soils from the results of laboratory tests. The application and use of this chart are discussed in greater detail under a subsequent heading in this manual.

Soil groups and group symbols

6. Major divisions. Soils are primarily divided into coarse-grained soils, fine-grained soils, and highly organic soils. On a textural basis, coarse-grained soils are those that have 50 per cent or less of the constituent material passing the No. 200 sieve, and fine-grained soils are those that have more than 50 per cent passing the No. 200 sieve. Highly organic soils are in general readily identified by visual examination. The coarse-grained soils are subdivided into gravel and gravelly soils (symbol G), and sands and sandy soils (symbol S). Fine-grained soils are subdivided on the basis of the liquid limit, symbol L is used for soils with liquid limits of 50 and less, and symbol H for soils with liquid limits in excess of 50 (see plate 2). Peat and other highly organic soils are designated by the symbol Pt and are not subdivided.

7. Subdivisions, coarse-grained soils. In general practice there is no clear-cut boundary between gravelly soils and sandy soils, and as far as behavior is concerned the exact point of division is relatively unimportant. For purposes of identification, coarse-grained soils are classed as gravels (G) if the greater percentage of the coarse fraction (retained on No. 200 sieve) is larger than the No. 4 sieve and as sands (S) if the greater portion of the coarse fraction is finer than the No. 4

sieve. Borderline cases may be classified as belonging to both groups. The gravel (G) and sand (S) groups are each divided into four secondary groups as follows

- a. Well-graded material with little or no fines. Symbol W. Groups GW and SW.
- b. Poorly-graded material with little or no fines. Symbol P. Groups GP and SP.
- c. Coarse material with nonplastic fines or fines with low plasticity. Symbol M. Groups GM and SM.
- d. Coarse material with plastic fines. Symbol C. Groups GC and SC.

8. Subdivisions, fine-grained soils. The fine-grained soils are subdivided into groups based on whether they have a relatively low (L) or high (H) liquid limit. These two groups are further subdivided as follows:

- a. Inorganic silts and very fine sandy soils, silty or clayey fine sands; micaceous and diatomaceous soils, elastic silts. Symbol M. Groups ML and MH.
- b. Inorganic clays. Symbol C. Groups CL and CH.
- c. Organic silts and clays. Symbol O. Croups OL and CH.

Discussion of Coarse-grained Soils

GW and SW groups

9. These groups comprise well-graded gravelly and sandy soils having little or no nonplastic fines (less than 5 per cent passing the No. 200 sieve). The presence of the fines must not noticeably change the strength characteristics of the coarse-grained fraction and must not interfere with its free-draining characteristics. If the material contains less than 5 per cent fines that exhibit plasticity, this

information should be evaluated and the soil classified as discussed subsequently under "Laboratory Identification." In areas subject to frost action, the material should not contain more than about 3 per cent of soil grains smaller than 0.02 mm in size. Typical examples of GW and SW soils are shown on plate 3.

GP and SP groups

10. Poorly-graded gravels and sands containing little or no nonplastic fines (less than 5 per cent passing the No. 200 sieve) are classed in the GP and SP groups. The materials may be classed as uniform gravels, uniform sands, or nonuniform mixtures of very coarse material and very fine sand, with intermediate sizes lacking (sometimes called skip-graded, gap-graded, or step-graded). The latter group often results from borrow excavation in which gravel and sand layers are mixed. If the fine fraction exhibits plasticity, this information should be evaluated and the soil classified as discussed subsequently under "Laboratory Identification." Typical examples of various types of GP and SP soils are shown on plate 4.

GM and SM groups

11. In general, the GM and SM groups comprise gravels or sands with fines (more than 12* per cent passing the No. 200 sieve) having low or no plasticity. The plasticity index and liquid limit (based on minus No. 40 sieve fraction) of soils in the group should plot below the "A" line on

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* In the preceding two paragraphs soils of the GW, GP, SW, and SP groups were defined as having less than 5 per cent passing the No. 200 sieve. Soils which have between 5 and 12 per cent passing the No. 200 sieve are classed as "borderline" and are discussed in paragraph 33 under that heading.

the plasticity chart. The gradation of the materials is not considered significant and both well- and poorly-graded materials are included. Some of the sands and gravels in this group will have a binder composed of natural cementing agents, so proportioned that the mixture shows negligible swelling or shrinkage. Thus the dry strength of such materials is provided by a small amount of soil binder or by cementation of calcareous material or iron oxide. The fine fraction of other materials in the GM and SM groups may be composed of silts or rock flour types having little or no plasticity and the mixture will exhibit no dry strength. Typical examples of types of GM and SM soils are shown on plate 5.

GC and SC groups

12. In general, the GC and SC groups comprise gravelly or sandy soils with fines (more than 12 per cent passing the No. 200 sieve) which have either low or high plasticity. The plasticity index and liquid limit of soils (fraction passing the No. 40 sieve) in the group should plot above the "A" line on the plasticity chart. The gradation of the materials is not considered significant and both well- and poorly-graded materials are included. The plasticity of the binder fraction has more influence on the behavior of the soils than does variation in gradation. The fine fraction is generally composed of clays. Typical examples of GC and SC soils are shown on plate 6.

Discussion of Fine-grained Soils

ML and MH groups

13. In these groups the symbol M has been used to designate

predominantly silty materials and micaceous or diatomaceous soils. The symbols L and H represent low and high liquid limits, respectively, and an arbitrary dividing line between the two is set at a liquid limit of 50. The soils in the ML and MH groups are sandy silts, clayey silts, or inorganic silts with relatively low plasticity. Also included are loess-type soils and rock flours. Micaceous and diatomaceous soils generally fall within the MH group but may extend into the ML group when their liquid limit is less than 50. The same is true for certain types of kaolin clays and some illite clays having relatively low plasticity. Typical examples of soils in the ML and MH groups are shown on plate 7.

CL and CH groups

14. In these groups the symbol C stands for clay, with L and H denoting low or high liquid limit. The soils are primarily inorganic clays. Low plasticity clays are classified as CL and are usually lean clays, sandy clays, or silty clays. The medium and high plasticity clays are classified as CH. These include the fat clays, gumbo clays, certain volcanic clays, and bentonite. The glacial clays of the northern United States cover a wide band in the CL and CH groups. Typical examples of soils in these groups are shown on plate 8.

OL and OH groups

15. The soils in the OL and OH groups are characterized by the presence of organic matter, hence the symbol O. Organic silts and clays are classified in these groups. The materials have a plasticity range that corresponds with the ML and MH groups. Typical examples of OL and OH soils are presented on plate 9.

Discussion of Highly Organic Soils

Pt group

16. The highly organic soils usually are very compressible and have undesirable construction characteristics. They are not subdivided and are classified into one group with the symbol Pt. Peat, humus, and swamp soils with a highly organic texture are typical soils of the group. Particles of leaves, grass, branches, or other fibrous vegetable matter are common components of these soils.

Identification of Soil Groups

17. The unified soil classification is so arranged that most soils may be classified into at least the three primary groups (coarse grained, fine grained, and highly organic) by means of visual examination and simple field tests. Classification into the subdivisions can also be made by visual examination with some degree of success. More positive identification may be made by means of laboratory tests on the materials. However, in many instances a tentative classification determined in the field is of great benefit and may be all the identification that is necessary, depending on the purposes for which the soils in question are to be used. Methods of general identification of soils are discussed in the following paragraphs, and a laboratory testing procedure is presented. It is emphasized that the two methods of identification are never entirely separated. Certain characteristics can only be estimated by visual examination, and in borderline cases it may be necessary to verify the classification by laboratory tests. Conversely, the field

methods are entirely practical for preliminary laboratory identification and may be used to advantage in grouping soils in such a manner that only a minimum number of laboratory tests need be run.

General Identification

18. The easiest way of learning field identification of soils is under the guidance of experienced personnel. Without such assistance, field identification may be learned by systematically comparing the numerical test results for typical soils in each group with the "feel" of the material while field identification procedures are being performed.

Coarse-grained soils

19. Texture and composition. In field identification of coarse-grained materials a dry sample is spread on a flat surface and examined to determine gradation, grain size and shape, and mineral composition. Considerable experience is required to differentiate, on the basis of a visual examination, between well-graded and poorly-graded soils. The durability of the grains of a coarse-grained soil may require a careful examination, depending on the use to which the soil is to be put. Pebbles and sand grains consisting of sound rock are easily identified. Weathered material is recognized from its discolorations and the relative ease with which the grains can be crushed. Gravels consisting of weathered granitic rocks, quartzite, etc., are not necessarily objectionable for construction purposes. On the other hand, coarse-grained soils containing fragments of shaley rock may be unsuitable because alternate wetting and drying may result in their partial or complete disintegration. This property can be identified by a slaking test.

The particles are first thoroughly oven- or sun-dried, then submerged in water for at least 24 hours, and finally their strength is tested and compared with the original strength. Some types of shales will completely disintegrate when subjected to such a slaking test.

20. Examination of fine fraction. Reference to the identification sheet (table 1) shows that classification criteria of the various coarse-grained soil groups are based on the amount of material passing the No. 200 sieve and the plasticity characteristics of the binder fraction (passing the No. 40 sieve). Various methods may be used to estimate the percentage of material passing the No. 200 sieve; the choice of method will depend on the skill of the technician, the equipment at hand, and the time available. One method, decantation, consists of mixing the soil with water in a suitable container and pouring off the turbid mixture of water and fine soil; successive decantations will remove practically all of the fines and leave only the sand and gravel sizes in the container. A visual comparison of the residue with the original material will give some idea of the amount of fines present. Another useful method is to put a mixture of soil and water in a test tube, shake it thoroughly, and allow the mixture to settle. The coarse particles will fall to the bottom and successively finer particles will be deposited with increasing time; the sand sizes will fall out of suspension in 20 to 30 seconds. If the assumption is made that the soil weight is proportional to its volume, this method may be used to estimate the amount of fines present. A rough estimate of the amount of fines may be made by spreading the sample out on a level surface and making a visual estimate of the percentage of fine particles present. The presence of fine sand can

usually be detected by rubbing a sample between the fingers, silt or clay particles feel smooth and stain the fingers, whereas the sand feels gritty and does not leave a stain. The "teeth test" is sometimes used for this purpose, and consists of biting a portion of the sample between the teeth. Sand feels gritty whereas silt and clay do not; clay tends to stick to the teeth while silt does not. If there appears to be more than about 12 per cent of the material passing the No. 200 sieve, the sample should be separated as well as possible by hand, or by decantation and evaporation, removing all of the gravel and coarse sand, and the characteristics of the fine fraction determined. The binder is mixed with water and its dry strength and plasticity characteristics are examined. Criteria for dry strength are shown in column 5 of the classification sheet, table 1; evaluation of soils according to dry strength and plasticity criteria is discussed in succeeding paragraphs in connection with fine-grained soils. Identification of active cementing agents other than clay usually is not possible by visual and manual examination, since such agents may require a curing period of days or even weeks. In the absence of such experience the soils should be classified tentatively into their apparent groups, neglecting any possible development of strength because of cementation.

Fine-grained soils

21. The principal procedures for field identification of fine-grained soils are the test for dilatancy (reaction to shaking), the examination of plasticity characteristics, and the determination of dry strength. In addition, observations of color and odor are of value, particularly for organic soils. Descriptions of the field identification

procedures are presented in the following paragraphs. The dilatancy, plasticity, and dry strength tests are performed on the fraction of the soil finer than the No. 40 sieve. Separation of particles coarser than the No. 40 sieve is done most expediently in the field by hand. However, separation by hand probably will be most effective for particles coarser than the No. 10 sieve. Some effort should be made to remove the No. 10 to No. 40 fraction but it is believed that any particles in this size range remaining after hand separation would have little effect on the field identification procedures.

22. Dilatancy. The soil is prepared for test by removing particles larger than about the No. 40 sieve size (by hand) and adding enough water, if necessary, to make the soil soft but not sticky. The pat of moist soil should have a volume of about 1/2 cubic inch. The pat of soil is alternately shaken horizontally in the open palm of one hand, which is struck vigorously against the other hand several times, and then squeezed between the fingers. A fine-grained soil that is nonplastic or exhibits very low plasticity will become livery and show free water on the surface while being shaken. Squeezing will cause the water to disappear from the surface and the sample to stiffen and finally crumble under increasing finger pressure, like a brittle material. If the water content is just right, shaking the broken pieces will cause them to liquefy again and flow together. A distinction may be made between rapid, slow, or no reaction to the shaking test, depending on the speed with which the pat changes its consistency and the water on the surface appears or disappears. Rapid reaction to the shaking test is typical for nonplastic, uniform fine sand, silty sand (SP, SM), and inorganic silts (ML)

particularly of the rock-flour type, also for diatomaceous earth (MH). The reaction becomes somewhat more sluggish with decreasing uniformity of gradation (and increase in plasticity up to a certain degree). Even a slight content of colloidal clay will impart to the soil some plasticity and slow up materially the reaction to the shaking test. Soils which react in this manner are somewhat plastic inorganic and organic silts (ML, OL), very lean clays (CL), and some kaolin-type clays (ML, MH). Extremely slow or no reaction to the shaking test is characteristic of all typical clays (CL, CH) as well as of highly plastic organic clays (OH).

23. Plasticity characteristics. Examination of the plasticity characteristics of fine-grained soils or of the fine fraction of coarse-grained soils is made with a small moist sample of the material. Particles larger than about the No. 40 sieve size are removed (by hand) and a specimen of soil about the size of a 1/2-in. cube is molded to the consistency of putty. If the soil is too dry, water must be added and if it is sticky, the specimen should be spread out in a thin layer and allowed to lose some moisture by evaporation. The sample is rolled by hand on a smooth surface or between the palms into a thread about 1/8 in. in diameter. The thread is then folded and rerolled repeatedly. During this manipulation the moisture content is gradually reduced and the specimen stiffens, finally loses its plasticity, and crumbles when the plastic limit is reached. After the thread crumbles, the pieces should be lumped together and a slight kneading action continued until the lump crumbles. The higher the position of a soil above the "A" line on the plasticity chart, plate 2 (CL, CH), the stiffer are the threads as their water content approaches the plastic limit and the tougher are the lumps as the

soil is remolded after rolling. Soils slightly above the "A" line (CL, CH) form a medium tough thread (easy to roll) as the plastic limit is approached but when the threads are formed into a lump and kneaded below the plastic limit, the soil crumbles readily. Soils below the "A" line (ML, MH, OL, OH) form a weak thread and, with the exception of the OH soils, cannot be lumped together into a coherent mass below the plastic limit. Plastic soils containing organic material or much mica (well below the "A" line) form threads that are very soft and spongy near the plastic limit. The binder fraction of coarse-grained soils may be examined in the same manner as fine-grained soils. In general, the binder fraction of coarse-grained soils with silty fines (GM, SM) will exhibit plasticity characteristics similar to the ML soils, and that of coarse-grained soils with clayey fines (GC, SC) will be similar to the CL soils.

24. Dry strength. The resistance of a piece of dried soil to crushing by finger pressure is an indication of the character of the colloidal fraction of a soil. To initiate the test, particles larger than the No. 40 sieve size are removed from the soil (by hand) and a specimen is molded to the consistency of putty, adding water if necessary. The moist pat of soil is allowed to dry (in oven, sun, or air) and is then crumbled between the fingers. Soils with slight dry strength crumble readily with very little finger pressure. All nonplastic ML and MH soils have almost no dry strength. Organic silts and lean organic clays of low plasticity (OL), as well as very fine sandy soils (SM), have slight dry strength. Soils of medium dry strength require considerable finger pressure to powder the sample. Most clays of the CL group and some OH soils exhibit medium dry strength. This is also true of the fine

fraction of gravelly and sandy soils having a clay binder (GC and SC). Soils with high dry strength can be broken but cannot be powdered by finger pressure. High dry strength is indicative of most CH clays, as well as some organic clays of the OH group having very high liquid limits and located near the A-line. In some instances high dry strength in the undisturbed state may be furnished by a cementing material such as calcium carbonate or iron oxide.

25. Color. In field soil surveys color is often helpful in distinguishing between various soil strata, and to an engineer with sufficient preliminary experience with the local soils, color may also be useful for identifying individual soils. The color of the moist soil should be used in identification as soil color may change markedly on drying. To the experienced eye certain dark or drab shades of gray or brown, including almost black colors, are indicative of fine-grained soils containing organic colloidal matter (OL, OH). In contrast, brighter colors, including medium and light gray, olive green, brown, red, yellow, and white, are generally associated with inorganic soils. Use of the Munsell soil color charts and plates, prepared for the U. S. Department of Agriculture by the Munsell Color Company, Baltimore, Maryland, is suggested in the event more precise soil color descriptions are desired or to facilitate uniform naming of soil colors.

26. Odor. Organic soils of the OL and OH groups usually have a distinctive odor which, with experience, can be used as an aid in the identification of such materials. This odor is especially apparent from fresh samples. It gradually diminishes on exposure to air, but can be revived by heating a wet sample.

Highly organic soils

27. The field identification of highly organic soils (group Pt) is relatively easy inasmuch as these soils are characterized by undecayed or partially carbonized particles of leaves, sticks, grass, and other vegetable matter which impart to the soil a typical fibrous texture. The color ranges generally from various shades of dull brown to black. A distinct organic odor is also characteristic of the soil. The water content is usually very high. Another aid in identification of these soils may be the location of the soil with respect to topography: low-lying, swampy areas usually contain highly organic soils.

Laboratory Identification

28. The identification of soils in the laboratory is accomplished by determining the gradation and plasticity characteristics of the materials. The gradation is determined by sieve analysis and a grain-size curve is usually plotted as per cent finer (or passing) by weight against a logarithmic scale of grain size in millimeters. Plate 1 is a typical grain-size chart. Plasticity characteristics are evaluated by means of the liquid and plastic limits tests on the soil fraction finer than the No. 40 sieve. A suggested laboratory method of identification is presented schematically in the chart shown as table 2 and is discussed in the succeeding paragraphs. It should be recognized that although a definite procedure for identification is outlined on the chart, the laboratory technician engaged in classification may be able to use "short cuts" in his work after he becomes thoroughly familiar with the criteria for each soil group.

Identification of major soil groups

29. Reference to the identification procedure chart, table 2, shows that the first step in the laboratory identification of a soil is to determine whether it is coarse grained, fine grained, or highly organic. This may be done by visual examination in most cases, using the procedures outlined for field identification. In some borderline cases, as with very fine sands or coarse silts, it may be necessary to screen a representative dry sample over a No. 200 sieve and determine the percentage passing. Fifty per cent or less passing the No. 200 sieve identifies the soil as coarse grained, and more than 50 per cent identifies the soil as fine grained. The percentage limit of 50 has been selected arbitrarily for convenience in identification as it is obvious that a numerical difference of 1 or 2 in this percentage will make no significant change in the behavior of the soil. After the major group in which the soil belongs is established, the identification procedure is continued in accordance with the proper headings in the chart.

Identification of subgroups,
coarse-grained soils

30. Gravels (G) or sands (S). A complete sieve analysis is run on coarse-grained soils and the gradation curve is plotted on a grain-size chart. For some soils containing a substantial amount of fines, it may be desirable to supplement the sieve analysis with a hydrometer analysis in order to define the gradation curve below the No. 200 sieve size. Preliminary identification is made by determining the percentage of material in the gravel (above No. 4 sieve) and sand (No. 4 to No. 200 sieve) sizes. If there is a greater percentage of gravel than sand the material is

classed as gravel (G); if there is a greater percentage of sand than gravel the material is classed as sand (S). Once again the distinction between these groups is purely arbitrary for convenience in following the system. The next identification step is to determine the amount of material passing the No. 200 sieve. Since the subgroups are the same for gravels and sands, they will be discussed jointly in the following paragraphs.

31. GW, SW, GP, and SP groups. These groups comprise nonplastic soils having less than 5 per cent passing the No. 200 sieve and in which the fine fraction does not interfere with the soils' free-draining properties. If the above criteria are met, an examination is made of the shape of the grain-size curve. Materials that are well graded are classified as GW or SW; poorly-graded materials are classified as GP or SP. The grain-size distributions of well-graded materials generally plot as smooth and regular concave curves with no sizes lacking or no excess of material in any size range (plate 3); the uniformity coefficient (60 per cent grain diameter divided by the 10 per cent grain diameter) of well-graded gravels is greater than 4, and of well-graded sands is greater than 6. In addition, the gradation curves should meet the following qualification in order to be classed as well graded.

$$\frac{(D_{30})^2}{D_{60} \times D_{10}} \text{ between 1 and 3}$$

where D_{30} = grain diameter at 30 per cent passing

D_{60} = grain diameter at 60 per cent passing

D_{10} = grain diameter at 10 per cent passing

The foregoing expression, termed a coefficient of curvature, insures that the grading curve will have a concave curvature within relatively narrow limits for a given D_{60} and D_{10} combination. All gradations not meeting the foregoing criteria are classed as poorly graded. Thus, poorly-graded soils (GP, SP) are those having nearly straight line gradations (plate 4, fig. 1, curve 3), convex gradations, nearly vertical (uniform) gradations (plate 4, fig. 1, curve 1), and gradation curves with "humps" typical of skip-graded materials (plate 4, fig. 1, curve 2).

32. GM, SM, GC and SC groups. The soils in these groups are composed of those materials having more than a 12* per cent fraction passing the No. 200 sieve; they may or may not exhibit plasticity. For identification, the liquid and plastic limits tests are required on the fraction finer than the No. 40 sieve. The tests should be run on representative samples of moist material, and not on air- or oven-dried soils. This precaution is desirable as drying affects the limits values to some extent as will be explained further in the discussion of fine-grained soils. Materials in which the liquid limit and plasticity index plot below the "A" line on the plasticity chart (plate 2) are classed as GM or SM (plate 5). Gravels and sands in which the liquid limit and plasticity index plot above the "A" line on the plasticity chart are classed as GC or SC (plate 6). It is considered that in the identification of materials in these groups the plasticity characteristics overshadow the gradation characteristics; therefore, no distinction is made between well- and poorly-graded materials.

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* In the preceding paragraph soils of the GW, GP, SW, and SP groups were defined as having less than a 5 per cent fraction passing the No. 200 sieve. Soils having between 5 and 12 per cent passing the No. 200 sieve are classed as "borderline" and are discussed in paragraph 33.

33. <u>Borderline soils.</u> Coarse-grained soils containing between 5 and 12% material passing the No. 200 sieve are classed as borderline and carry a dual symbol, e.g , GW-GM. Similarly, coarse-grained soils having less than 5% passing the No. 200 sieve, but which are not free draining, or wherein the fine fraction exhibits plasticity, are also classed as borderline and are given a dual symbol. Additional discussion of borderline classification is presented in paragraphs 38-41.

Identification of subgroups, fine-grained soils

34. <u>Use of plasticity chart.</u> Once the identity of a fine-grained soil has been established, further identification is accomplished principally by the liquid and plastic limits tests in conjunction with the plasticity chart (plate 2). The plasticity chart was developed by Dr. Casagrande as the result of considerable experience with the behavior of soils in many different regions. It is a plot of liquid limit versus plasticity index on which is imposed a diagonal line called the "A" line and a vertical line at a liquid limit of 50. The "A" line is defined by the equation PI = 0.73 (LL-20). The "A" line above a liquid limit of about 29 represents an important empirical boundary between typical inorganic clays (CL and CH), which are generally located above the line, and plastic soils containing organic colloids (OL and OH) or inorganic silty soils (ML and MH). The vertical line at liquid limit of 50 separates silts and clays of low liquid limit (L) from those of high liquid limit (H). In the low part of the chart below a liquid limit of about 29 and in the range of PI from 4 to 7 there is considerable overlapping of the properties of the clayey and silty soil types. Hence, the separation between

CL and OL or ML soil types in this region is accomplished by a cross-hatched zone on the plasticity chart between 4 and 7 PI and above the "A" line. CL soils in this region are those having a PI above 7 while OL or ML soils are those having a PI below 4. Soils plotting within the cross-hatched zone should be classed as borderline as discussed later. The various soil groups are shown in their respective positions on the plasticity chart. Experience has shown that compressibility is approximately proportional to liquid limit and that soils having the same liquid limit possess approximately equal compressibility, assuming that other factors are essentially the same. On comparing the physical characteristics of soils having the same liquid limit, one finds that with increasing plasticity index, the cohesive characteristics increase and the permeability decreases. From plots of the results of limits tests on a number of samples from the same fine-grained deposit, it is found that for most soils these points lie on a straight line or in a narrow band approximately parallel to the "A" line. With this background information in mind, the identification of the various groups of fine-grained soils is discussed in the following paragraphs.

35. ML, CL, and OL groups. A soil having a liquid limit of less than 50 falls into the low liquid limit (L) group. A plot of the liquid limit and plasticity index on the plasticity chart will show whether it falls above or below the "A" line and cross-hatched zone. Soils plotting above the "A" line and cross-hatched zone are classed as CL and are usually typical inorganic clays (plate 8, fig. 1). Soils plotting below the "A" line or cross-hatched zone are inorganic silts or very fine sandy silts, ML (plate 7, fig. 1), or organic silts or organic silt-clays of low

plasticity, OL (plate 9, fig. 1). Since two groups fall below the "A" line or cross-hatched zone, further identification is necessary. The distinguishing factor between the ML and OL groups is the absence or presence of organic matter. This is usually identified by color and odor as explained in the preceding paragraphs under field identification. However, in doubtful cases a comparison may be made between the liquid and plastic limits of a moist sample and one that has been oven-dried. An organic soil will show a radical drop in plasticity after oven-drying or air-drying. An inorganic soil will generally show a change in the limits values of only 1 or 2% which may be either an increase or a decrease. For the foregoing reasons the classification should be based on the plot of limits values determined before drying. Soils containing organic matter generally have lower specific gravities and may have decidedly higher water contents than inorganic soils; therefore, these properties may be of assistance in identifying organic soils. In special cases, the determination of organic content may be made by chemical methods, but the procedures just described are usually sufficient.

36. MH, CH, and OH groups. Soils with a liquid limit greater than 50 are classed in group H. To identify such soils, the liquid limit and plasticity index values are plotted on the plasticity chart. If the points fall above the "A" line, the soil classifies as CH; if it falls below the "A" line, a determination is made as to whether or not organic material is present, as described in the preceding paragraph. Inorganic materials are classed as MH and organic materials are classed as OH.

Identification of highly organic soils

37. Little more can be said as to the laboratory identification of

highly organic soils (Pt) than has been stated previously under field identification. These soils are usually identified readily on the basis of color, texture, and odor Moisture determinations usually show a natural water content of several hundred per cent, which is far in excess of that found for most soils. Specific gravities of the solids in these soils may be quite low. Some peaty soils can be remolded and tested for liquid and plastic limits. Such materials usually have a liquid limit of several hundred per cent and fall well below the "A" line on the plasticity chart.

Borderline classifications

38. It is inevitable in the use of the classification system that soils will be encountered that fall close to the boundaries established between the various groups. In addition, boundary zones for the amount of material passing the No. 200 sieve and for the lower part of the plasticity chart have been incorporated as a part of the system, as discussed subsequently. The accepted rule in classifying borderline soils is to use a double symbol; for example, GW-GM. It is possible, in rare instances, for a soil to fall into more than one borderline zone and, if appropriate symbols were used for each possible classification, the result would be a multiple designation consisting of three or more symbols. This approach is unnecessarily complicated and it is considered best to use only a double symbol in these cases, selecting the two that are believed most representative of the probable behavior of the soil. In cases of doubt the symbols representing the poorer of the possible groupings should be used.

39. Coarse-grained soils. It will be recalled that in previous

discussions (paragraph 31) the coarse-grained soils were classified in the GW, GP, SW, and SP groups if they contained less than 5% of material passing the No. 200 sieve. Similarly, soils were classified in the GM, GC, SM, and SC groups if they had more than 12% passing the No. 200 sieve (paragraph 32). The range between 5 and 12% passing the No. 200 seive is designated as borderline, and soils falling within it are assigned a double symbol depending on both the gradation characteristics of the coarse fraction and the plasticity characteristics of the minus No. 40 sieve fraction. For example, a well-graded sandy soil with 8% passing the No. 200 sieve and with LL = 28 and PI = 9 would be designated as SW-SC. Another type of borderline classification occurs for those soils containing appreciable amounts of fines, groups GM, GC, SM, and SC, and whose Atterberg limits values plot in the lower portion of the plasticity chart. The method of classifying these soils is the same as for fine-grained soils plotting in the same region, as presented in the following paragraph.

40. Fine-grained soils. Mention has been made of a zone on the plasticity chart (plate 2) below a liquid limit of about 29 and ranging between plasticity index values of 4 and 7. Several soil types exhibiting low plasticity plot in this general region on the plasticity chart and no definite boundary between silty and clayey soils exists. Thus, if a fine-grained soil, groups CL and ML, or the minus No. 40 sieve fraction of a coarse-grained soil, groups GM, GC, SM, and SC, plots within the cross-hatched zone on the plasticity chart, a double symbol (ML-CL, etc.) is used.

41. "Silty" and "clayey." It will be noted on the classification sheet, table 1, that the adjectives "silty" and "clayey" may be used as part of the descriptive name for silt or clay soils. Since the

definitions of these terms are now somewhat different from those used by many soils engineers, it is considered advisable to discuss their connotation as used in this system In the unified soil classification the terms "silt" and "clay" are used to describe those soils with Atterberg limits plotting respectively below and above the "A" line and cross-hatched zone on the plasticity chart. As a logical extension of this concept, the terms "silty" and "clayey" may be used as adjectives in the soil names when the limits values plot close to the "A" line. For example, a clay soil with LL = 40 and PI = 16 may be called a silty clay. In general, the adjective "silty" is not applied to clay soils having a liquid limit in excess of about 60.

Expansion of Classification

42. It may be necessary, in some cases, to expand the unified classification system by subdivision of existing groups in order to classify soils for a particular use. The indiscriminate use of subdivisions is discouraged and careful study should be given any soil group before such a step is adopted. In all cases subdivisions should be designated preferably by a suffix to an existing group symbol. The suffix should be selected carefully so that there will be no confusion with existing letters that already have meanings in the classification system. In each case where an existing group is subdivided, the basis and criteria for the subdivision should be explained in order that anyone unfamiliar with it may understand the subdivision properly.

Descriptive Soil Classification

43. At many stages in the soils investigation of a project -- from the preliminary boring log to the final report -- the engineer finds it convenient to give the soils he is working with a "name" rather than an "impersonal" classification symbol such as GC. This results primarily from the fact that he is accustomed to talking in terms of gravels, sands, silts, and clays, and finds it only logical to use these same names in presenting the data. The soil names have been associated with certain grain sizes in the textural classification as shown on the grain-size chart, plate 1. Such a division is generally feasible for the coarse-grained soils; however, the use of such terms as silt and clay may be entirely misleading on a textural basis. For this reason the terms "silt" and "clay" have been defined on a plasticity basis as discussed previously. Within a given region of the country, use of a name classification based on texture is often feasible since the general behavior of similar soils is consistent over the area. However, in another area the same classification may be entirely inadequate. The descriptive classification, if used intelligently, has a rightful place in soil mechanics, but its use should be carefully evaluated by all concerned.

Description from classification sheet

44. Column 4 of the classification sheet, table 1, lists typical names given the soil types usually found within the various classification groups. By following either the field or laboratory investigation procedure and determining the proper classification group in which the soil

belongs, it is usually an easy matter to select an appropriate name from the classification sheet. Some soils may be readily identified and properly named by only visual inspection. A word of caution is considered appropriate on the use of the classification system for certain soils such as marls, caliches, coral, shale, etc., where the grain size can vary widely depending on the amount of mechanical breakdown of soil particles. For these soils the group symbol and textural name have little significance and the locally used name may be important.

Other descriptive terms

45. Records of field explorations in the form of boring logs can be of great benefit to the engineer if they include adequate information. In addition to the group symbol and the name of the soil, the general characteristics of the soils as to plasticity, strength, moisture, etc., provide information essential to a proper analysis of a particular problem. Locally accepted soil names should also be used to clarify the data to local bidders, and to protect the Government against later legal claims. For coarse-grained soils, the size of particles, mineralogical composition, shape of grains, and character of the binder are relevant features. For fine-grained soils, strength, moisture, and plasticity characteristics are important. When describing undisturbed soils such characteristics as stratification, structure, consistency in the undisturbed and remolded states, cementation, drainage, etc., are pertinent to the descriptive classification. Pertinent items to be used in describing soils are shown in column 6 of table 1. In order to achieve uniformity in estimating consistency of soils, it is recommended that the Terzaghi classification based on unconfined compressive strength be

used as a tentative standard. This classification is given below:

Unconfined Compressive Strength Tons/Sq Ft	Consistency
< 0.25	Very soft
0.25-0.50	Soft
0.50-1.00	Medium
1.00-2.00	Stiff
2.00-4.00	Very stiff
> 4.00	Hard

Several examples of descriptive classifications are shown below:

a. Uniform, fine, clean sand with rounded grains (SP).

b. Well-graded gravelly silty sand, angular chert gravel, 1/2-in. maximum size; silty binder with low plasticity, well-compacted and moist (SM).

c. Light brown, fine, sandy silt; very low plasticity; saturated and soft in the undisturbed state (ML).

d. Dark gray, fat clay; stiff in the undisturbed state; soft and sticky when remolded (CH).

(1a

Major Divisions			Group Symbols	Typical Names	Field Identification (Excluding particles larger than 3 in and basing fractions on estimated)	
1	2		3	4		
Coarse grained Soils. More than half of material is larger than No 200 sieve size. The No 200 sieve size is about the smallest particle visible to the naked eye	Gravels. More than half of coarse fraction is larger than No 4 sieve size. (For visual classification, the 1/4 in size may be used as equivalent to the No 4 sieve size)	Clean Gravels (Little or no fines)	GW	Well-graded gravels gravel-sand mixtures little or no fines	Wide range in grain sizes and amounts of all intermediate	
			GP	Poorly graded gravels or gravel sand mixtures, little or no fines	Predominantly one size or a range with some intermediate sizes m	
		Gravels with Fines (Appreciable amount of fines)	GM	Silty gravels gravel-sand silt mixture	Nonplastic fines or fines w (For identification proce	
			GC	Clayey gravels gravel-sand-clay mixtures	Plastic fines (for identifi see CL below)	
	Sands. More than half of coarse fraction is smaller than No 4 sieve size	Clean Sands (Little or no fines)	SW	Well-graded sands gravelly sands little or no fines	Wide range in grain size an of all intermediate parti	
			SP	Poorly graded sands or gravelly sands little or no fines	Predominantly one size or a with some intermediate si	
		Sands with Fines (Appreciable amount of fines)	SM	Silty sands sand-silt mixtures	Nonplastic fines or fines w (for identification proce	
			SC	Clayey sands sand clay mixtures	Plastic fines (for ident fi see CL below)	
Fine grained Soils. More than half of material is smaller than No 200 sieve size					Identification on Fraction Smaller than	
					Dry Strength (Crushing characteristics)	Dilatancy (Reaction to shaking)
	Silts and Clays. Liquid limit is less than 50		ML	Inorganic silts and very fine sands rock flour silty or clayey fine sands or clayey silts with slight plasticity	None to slight	Quick to s
			CL	Inorganic clays of low to medium plasticity gravelly clays sandy clays silty clays lean clays	Medium to high	None to very slow
			OL	Organic silts and organic silty clays of low plasticity	Slight to medium	Slow
	Silts and Clays. Liquid limit is greater than 50		MH	Inorganic silts micaceous or diatomaceous fine sandy or silty soils elastic silts	Slight to medium	Slow to no
			CH	Inorganic clays of high plasticity fat clays	High to very high	None
			OH	Organic clays of medium to high plasticity organic silts	Medium to high	None to very slow
Highly Organic Soils			Pt	Peat and other highly organic soils	Readily identified by colo and frequently by f brou	

(1) Boundary classifications. Soils possessing characteristics of two groups are designated by combinations of grou

FIELD IDENTIFICA

These procedures are to be performed on the minus N
screening is not intended simply

Dilatancy (reaction to shaking)

After removing particles larger than No 40 sieve size prepare a pat of moist soil with a volume of about one-half cubic inch Add enough water if necessary to make the soil soft but not sticky

Place the pat in the open palm of one hand and shake horizontally striking vigorously against the other hand several times A positive reaction consists of the appearance of water on the surface of the pat which changes to a livery consistency and becomes glossy When the sample is squeezed between the fingers, the water and gloss disappear from the surface the pat stiffens and finally it cracks or crumbles The rapidity of appearance of water during shaking and of its disappearance during squeezing assist in identifying the character of the fines in a soil

Very fine clean sands give the quickest and most distinct reaction whereas a plastic clay has no reaction Inorganic silts such as a typical rock flour show a moderately quick reaction

Dry Strength (crushing cha

After removing particles consistency of putty by oven sun, or air-d between the fingers the colloidal fraction increasing plasticity

High dry strength is cha ganic silt possesses a have about the same al when powdering the dri has the smooth feel of

Table 1

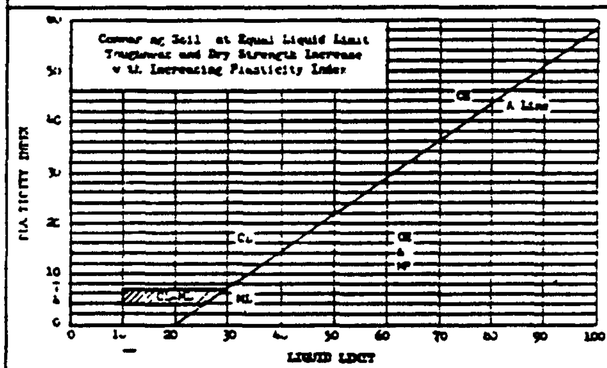
UNIFIED SOIL CLASSIFICATION
(Including Ident f cat on and Descr p on)

Field Iden fica ion Procedures (Excluding part cles larger than 3 in and basing fractions on estimated weights)	Informat on Required for Describing Soils	Laboratory C a f cat n Criter a		
	6			
de range in grain s zes and substantial amounts of all intermediate particle size	For und sturbed so l add informat on on or tr t f cation degree o compact ess cementation mo sture cond tion and drainage characterist c	Determine percentages f gravel and sand from grain si e curve. Depending on percentage of fines (fraction smaller than No. 200 sieve size) coarse grained soils are classified as follows: Less than 5% GW, GP, SW, SP; More than 12% GM, GC, SM, SC; 5% to 12% Borderline cases requiring use of dual symbols	$C_u = \frac{D_{60}}{D_{10}}$ Greater than 4; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between 1 and 3	
dominantly one size or a range of sizes with some intermediate sizes missing			Not meeting all gradation requirements for GW	
plastic fines or fines with low plasticity (for identification procedures see ML below)	Give typical name indicate approximate percentages of sand and gravel maximum s ze angular ty surface condition and hardness of the coarse grains loca or geolog c name and other pertinent descr ptive information and symbol in parentheses.		Atterberg limits below "A" line or PI less than 4	Above "A" line with PI between 4 and 7 are borderline cases requiring use of dual symbols
astic fines (for identification procedures see CL below)			Atterberg limits above "A" line with PI greater than 7	
de range in grain size and substantial amounts f all intermediate particle sizes			$C_u = \frac{D_{60}}{D_{10}}$ Greater than 6; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between 1 and 3	
dominantly one size or a range of sizes with some intermediate sizes missing	Example: Silty sand, gravelly about 20% hard angular gravel particles 1/2 in maximum size rounded and subangular sand grains coarse to fine about 15% nonplastic fines with low dry strength well compacted and moist in place alluvial sand (SM)		Not meeting all gradation requirements for SW	
plastic fines or fines with low plasticity (for identification procedures see ML below)			Atterberg limits below "A" line or PI less than 4	Above "A" line with PI between 4 and 7 are borderline cases requiring use of dual symbols
astic fines (for identification procedures see CL below)			Atterberg limits above "A" line with PI greater than 7	

Use grain size curve in identifying the fractions as given under field identification

Identification Procedures on Fraction Smaller than No. 40 Sieve Size

Dry Strength (Crushing characteristics)	Dilatancy (Reaction to shaking)	Toughness (Consistency near PL)	Information Required for Describing Soils
e to slight	Quick to slow	None	For undisturbed soils add information on structure stratification consistency in undisturbed and remolded states moisture and drainage conditions
ium to high	None to very slow	Medium	
ht to dium	Slow	Slight	Give typical name indicate degree and character of plasticity amount and maximum size of coarse grains color in wet condition odor if any local or geologic name and other pertinent descriptive information and symbol in parentheses
ht to dium	Slow to none	Slight to medium	
h to very h	None	High	Example: Clayey silt, brown slightly plastic small percentage of fine sand numerous vertical root holes firm and dry in place loess (ML)
ium to high	None to very slow	Slight to medium	
ly identified by color, odor spongy feel and frequently by fibrous texture			



PLASTICITY CHART

For laboratory classification of fine-grained soil

combinations of group symbols For example GW-GC well-graded gravel-sand mixture with clay binder (2) All sieve sizes on this chart are U S standard

FIELD IDENTIFICATION PROCEDURES FOR FINE-GRAINED SOILS OR FRACTIONS

formed on the minus No. 40 sieve size particles approximately 1/64 in. For field classification purposes not intended simply remove by hand the coarse particles that interfere with the tests

Strength (crushing characteristics)

After removing particles larger than No. 40 sieve size mold a pat of soil to the consistency of putty adding water if necessary. Allow the pat to dry completely by oven sun or air-drying and then test its strength by breaking and crumbling between the fingers. This strength is a measure of the character and quantity of the colloidal fraction contained in the soil. The dry strength increases with increasing plasticity.

High dry strength is characteristic for clays of the CH group. A typical inorganic silt possesses only very slight dry strength. Silty fine sands and silts have about the same slight dry strength but can be distinguished by the feel when powdering the dried specimen. Fine sand feels gritty whereas a typical silt has the smooth feel of flour.

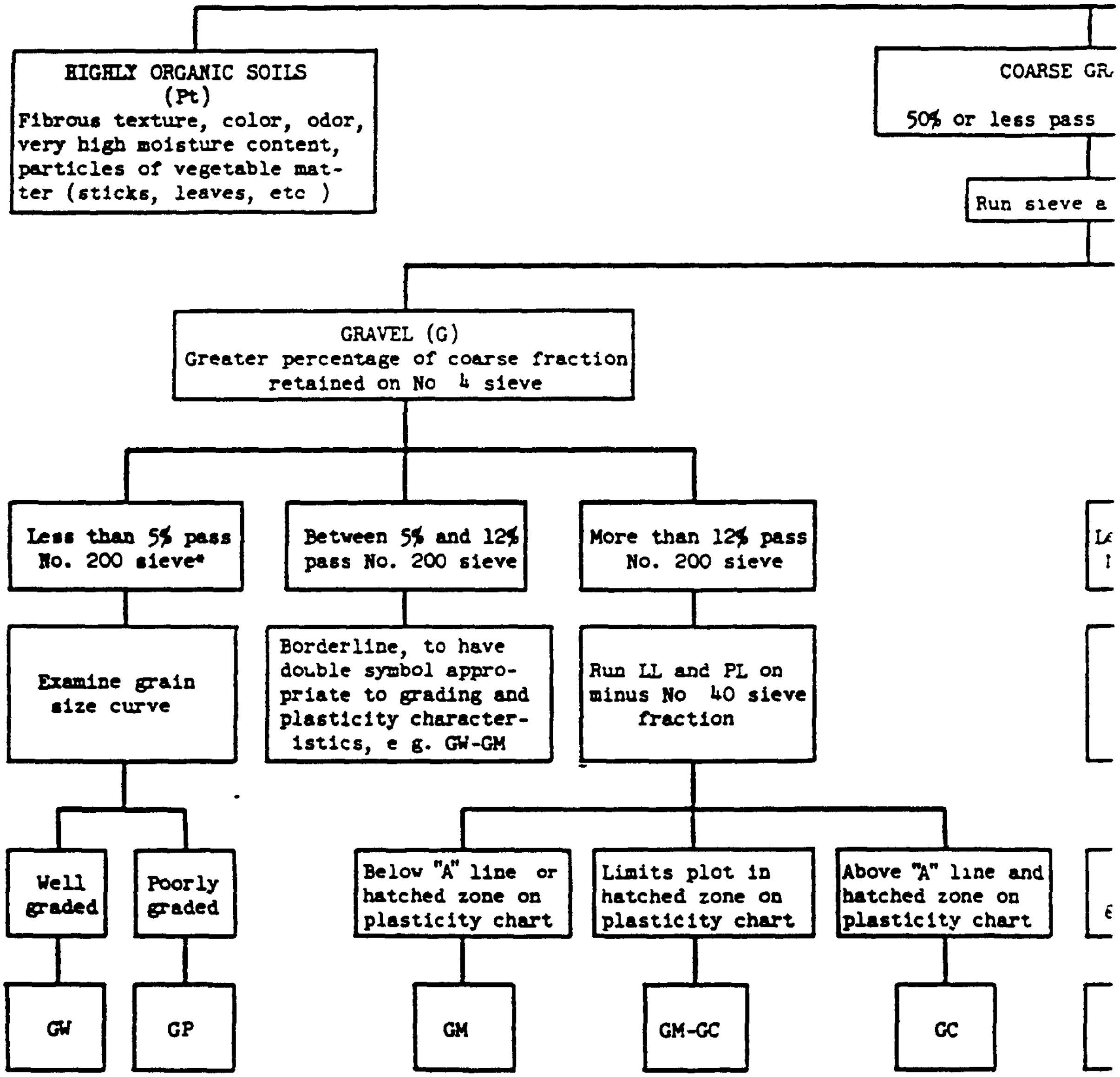
Toughness (consistency near plastic limit)

After particles larger than the No. 40 sieve size are removed a specimen of soil about one-half inch cube in size is molded to the consistency of putty. If too dry water must be added and if sticky the specimen should be spread out in a thin layer and allowed to lose some moisture by evaporation. Then the specimen is rolled out by hand on a smooth surface or between the palms into a thread about one-eighth inch in diameter. The thread is then folded and rerolled repeatedly. During this manipulation the moisture content is gradually reduced and the specimen stiffens finally loses its plasticity and crumbles when the plastic limit is reached.

After the thread crumbles the pieces should be lumped together and a slight kneading action continued until the lump crumbles.

The tougher the thread near the plastic limit and the stiffer the lump when it finally crumbles the more potent is the colloidal clay fraction in the soil. Weakness of the thread at the plastic limit and quick loss of coherence of the lump below the plastic limit indicate either inorganic clay of low plasticity or materials such as kaolin-type clays and organic clays which occur below the A-line.

Highly organic clays have a very weak and spongy feel at the plastic limit.



Note: Sieve sizes are U. S. Standard.

* If fines interfere with free draining properties use double symbol such as GW-GM, etc.

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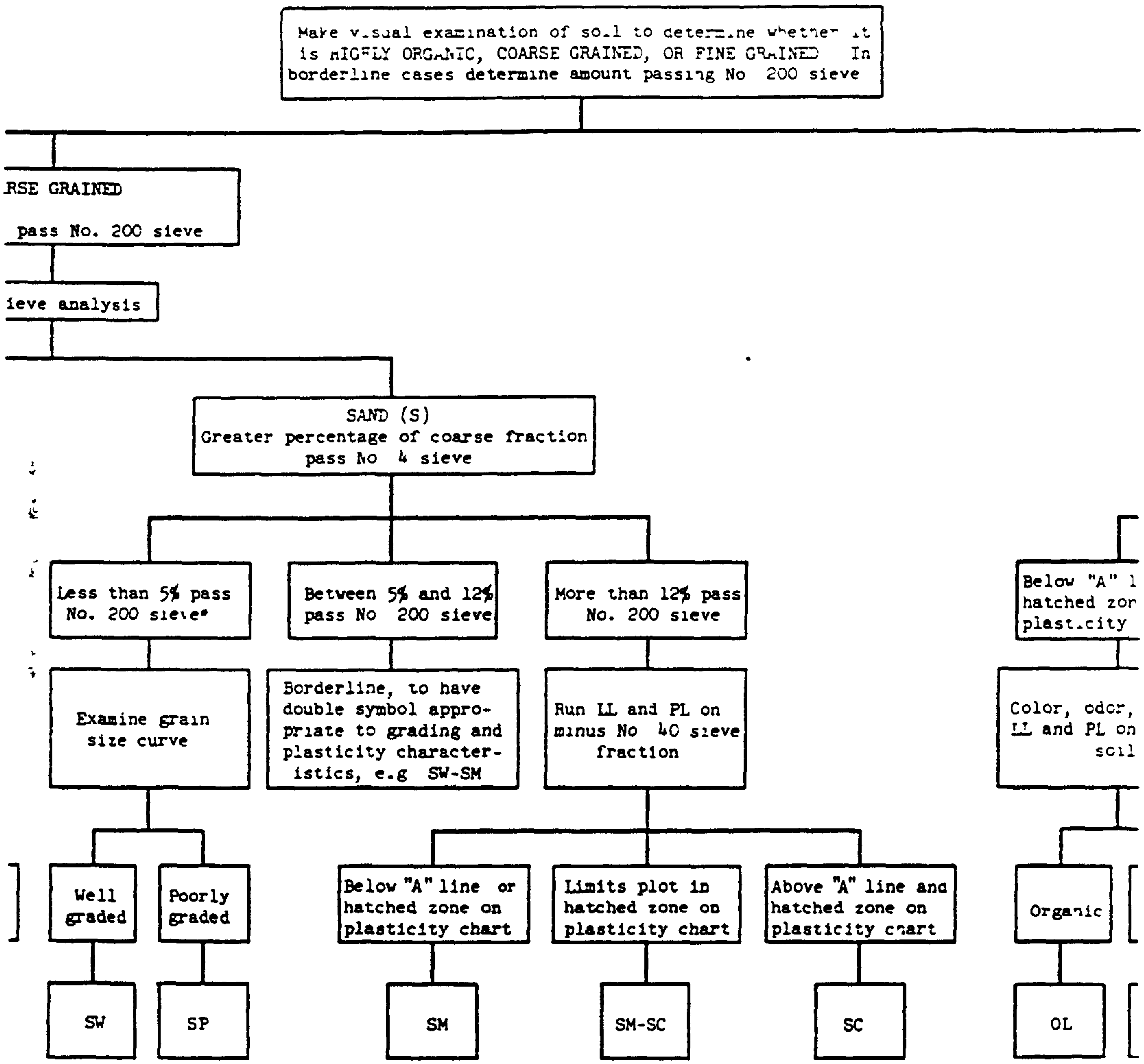
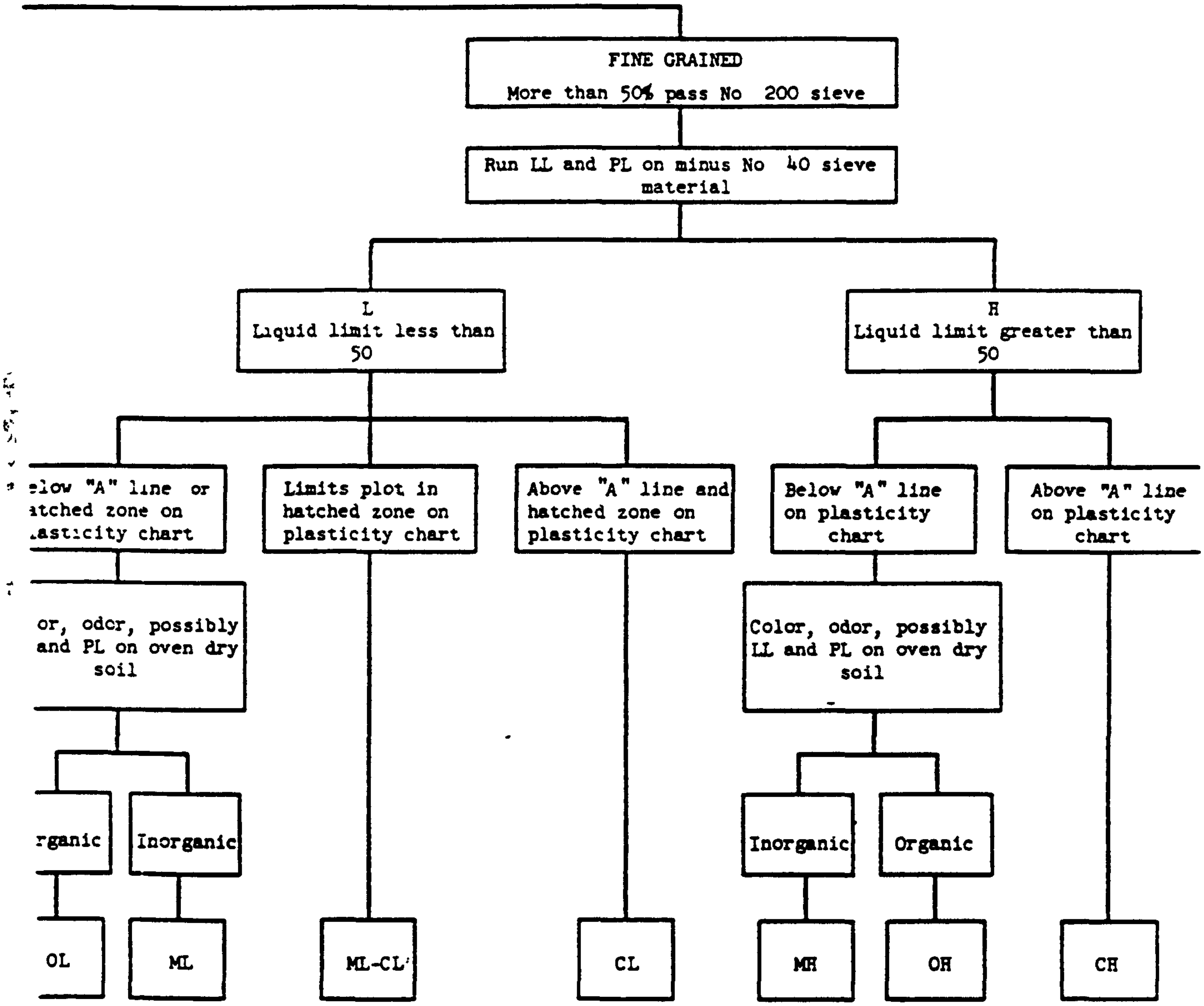
Table 2

AUXILIARY LABORATORY IDENTIFICATION PROCEDURE



tc


FINE GRAINED
More than 50% pass No 200 sieve
Run LL and PL on minus No 40 sieve material
L
Liquid limit less than 50
H
Liquid limit greater than 50
elow "A" line or
atched zone on
asticity chart
Limits plot in hatched zone on plasticity chart
Above "A" line and hatched zone on plasticity chart
Below "A" line on plasticity chart
Above "A" line on plasticity chart
or, odor, possibly
and PL on oven dry
soil
Color, odor, possibly LL and PL on oven dry soil
rganic
Inorganic
Inorganic
Organic
OL
ML
ML-CL
CL
MH
OH
CH

UNIFIED SOIL CLASSIFICATION SYSTEM

APPENDIX A

CHARACTERISTICS OF SOIL GROUPS PERTAINING TO EMBANKMENTS AND FOUNDATIONS

Introduction

1. The major properties of a soil proposed for use in an embankment or foundation that are of concern to the design or construction engineer are its strength, permeability, and consolidation and compaction characteristics. Other features may be investigated for a specific problem, but in general some or all of the properties mentioned above are of primary importance in an earth embankment or foundation project of any magnitude. It is common practice to evaluate the properties of the soils in question by means of laboratory or field tests and to use the results of such tests as a basis for design and construction. The factors that influence strength, consolidation, and other characteristics are numerous and some of them are not completely understood; consequently, it is impractical to evaluate these features by means of a general soils classification. However, the soil groups in a given classification do have reasonably similar behavior characteristics, and while such information is not sufficient for design purposes, it will give the engineer an indication of the behavior of a soil when used as a component in construction. This is especially true in the preliminary examination for a project when neither time nor money for a detailed soils testing program is available.

2. It should be borne in mind by engineers using the classification

that only generalized characteristics of the soil groups are included therein, and they should be used primarily as a guide and not as the complete answer to a problem For example, it is possible to design and construct an earth embankment of almost any type of soil and upon practically any foundation; this is in accordance with the worth-while principle of utilizing the materials available for construction. However, when a choice of materials is possible, certain of the available soils may be better suited to the job than others. It is on this basis that the behavior characteristics of soils are presented in the following paragraphs and on the classification sheet. The use to which a structure is to be put is often the principal deciding factor in the selection of soil types as well as the type of protective measures that will be utilized. Since each structure is a special problem within itself, it is impossible to cover all possible considerations in the brief description of pertinent soil characteristics contained in this appendix.

Features Shown on Soils Classification Sheet

3. General characteristics of the soil groups pertinent to embankments and foundations are presented in table A1. Columns 1 through 5 of the table show major soil divisions, group symbols, and hatching and color symbols; names of soil types are given in column 6. The basic features are the same as those presented in the soils classification manual. Columns 7 through 12 show the following: column 7, suitability of the materials for use in embankments (strength and permeability characteristics); column 8, the minimum or range of permeability values to be expected for the soil groups; columns 9 and 10, general compaction

characteristics; column 11, the suitability of the soils for foundations (strength and consolidation); and column 12, the requirements for seepage control, especially when the soils are encountered in the foundation for earth embankments (permeability). Brief discussions of these features are presented in the following paragraphs.

Suitability of soils for embankments

4. Three major factors that influence the suitability of soils for use in embankments are permeability, strength, and ease of compaction. The gravelly and sandy soils with little or no fines, groups GW, GP, SW, and SP, are stable, pervious, and attain good compaction with crawler-type tractors and rubber-tired rollers. The poorly-graded materials may not be quite as desirable as those which are well graded, but all of the materials are suitable for use in the pervious sections of earth embankments. Poorly-graded sands (SP) may be more difficult to utilize and, in general, should have flatter embankment slopes than the SW soils. The gravels and sands with fines, groups GM, GC, SM, and SC, have variable characteristics depending on the nature of the fine fraction and the gradation of the entire sample. These materials are often sufficiently impervious and stable to be used for impervious sections of embankments. The soils in these groups should be carefully examined to insure that they are properly zoned with relation to other materials in an embankment. Of the fine-grained soils, the CL group is best adapted for embankment construction; the soils are impervious, fairly stable, and give fair to good compaction with a sheepsfoot roller or rubber-tired roller. The MH soils, while not desirable for rolled-fill construction, may be utilized in the core of hydraulic-fill structures. Soils of

the ML group may or may not have good compaction characteristics, and in general must be closely controlled in the field to secure the desired strength. CH soils have fair stability when used on flat slopes but have detrimental shrinkage characteristics which may necessitate blanketing them or incorporating them in thin interior cores of embankments. Soils containing organic matter, groups OL, OH, and Pt, are not commonly used for embankment construction because of the detrimental effects of the organic matter present. Such materials may often be utilized to advantage in blankets and stability berms where strength is not of importance.

Permeability and seepage control

5. Since the permeability (column 8) and requirements for seepage control (column 12) are essentially functions of the same property of a soil, they will be discussed jointly. The subject of seepage in relation to embankments and foundations may be roughly divided into three categories: (1) seepage through embankments; (2) seepage through foundations; and (3) control of uplift pressures. These are discussed in relation to the soil groups in the following paragraphs.

6. Seepage through embankments. In the control of seepage through embankments, it is the relative permeability of adjacent materials rather than the actual permeability of such soils that governs their use in a given location. An earth embankment is not watertight and the allowable quantity of seepage through it is largely governed by the use to which the structure is put; for example, in a flood-control project considerable seepage may be allowed and the structure will still fulfill the storage requirements, whereas for an irrigation project much less seepage is

allowable because pool levels must be maintained. The more impervious soils (GM, GC, SM, SC, CL, MH, and CH) may be used in core sections or in homogeneous embankments to retard the flow of water. Where it is important that seepage not emerge on the downstream slope or the possibility of drawdown exists on upstream slopes, more pervious materials are usually placed on the outer slopes. The coarse-grained, free-draining soils (GW, GP, SW, SP) are best suited for this purpose. Where a variety of materials is available they are usually graded from least pervious to more pervious from the center of the embankment outward. Care should be used in the arrangement of materials in the embankment to prevent piping within the section. The foregoing statements do not preclude the use of other arrangements of materials in embankments. Dams have been constructed successfully entirely of sand (SW, SP, SM) or of silt (ML) with the section made large enough to reduce seepage to an allowable value without the use of an impervious core. Coarse-grained soils are often used in drains and toe sections to collect seepage water in downstream sections of embankments. The soils used will depend largely upon the material that they drain; in general, free-draining sands (SW, SP) or gravels (GW, GP) are preferred, but a silty sand (SM) may effectively drain a clay (CL, CH) and be entirely satisfactory.

7. Seepage through foundations. As in the case of embankments, the use of the structure involved often determines the amount of seepage control necessary in foundations. Cases could be cited where the flow of water through a pervious foundation would not constitute an excessive water loss and no seepage control measures would be necessary if adequate provisions were made against piping in critical areas. If seepage control

is desired, then the more pervious soils are the soils in which necessary measures must be taken. Free-draining gravels (GW, GP) are capable of carrying considerable quantities of water, and some means of positive control such as a cutoff trench may be necessary. Clean sands (SW, SP) may be controlled by a cutoff or by an upstream impervious blanket. While a drainage trench at the downstream toe or a line of relief wells will not reduce the amount of seepage, either will serve to control seepage and route the flow into collector systems where it can be led away harmlessly. Slightly less pervious material, such as silty gravels (GM), silty sands (SM), or silts (ML), may require a minor amount of seepage control such as that afforded by a toe trench, or if they are sufficiently impervious no control may be necessary. The relatively impervious soils (GC, SC, CL, OL, MH, CH, and OH) usually pass such a small volume of water that seepage control measures are not necessary.

8. Control of uplift pressures. The problem of control of uplift pressures is directly associated with pervious foundation soils. Uplift pressures may be reduced by lengthening the path of seepage (by a cutoff or upstream blanket) or by measures for pressure relief in the form of wells, drainage trenches, drainage blankets, or pervious downstream shells. Free-draining gravels (GW, GP) may be treated by any of the aforementioned procedures; however, to obtain the desired pressure relief, the use of a positive cutoff may be preferred, as blanket, well, or trench installations would probably have to be too extensive for economical accomplishment of the desired results. Free-draining sands (SW, SP) are generally less permeable than the gravels and, consequently, the volume of water that must be controlled for pressure relief is usually less.

Therefore a positive cutoff may not be required and an upstream blanket, wells, or a toe trench may be entirely effective. In some cases a combination of blanket and trench or wells may be desirable. Silty soils -- silty gravels (GM), silty sands (SM), and silts (ML) -- usually do not require extensive treatment; a toe drainage trench or well system may be sufficient to reduce uplift pressures. The more impervious silty materials may not be permeable enough to permit dangerous uplift pressures to develop and in such cases no treatment is indicated. In general, the more impervious soils (GC, SC, CL, OL, MH, CH, and OH) require no treatment for control of uplift pressures. However, they do assume importance when they occur as a relatively thin top stratum over more pervious materials. In such cases uplift pressures in the lower layers acting on the base of the impervious top stratum can cause heaving and formation of boils; treatment of the lower layer by some of the methods mentioned above is usually indicated in these cases. It is emphasized that control of uplift pressures should not be applied indiscriminately just because certain types of soils are encountered. Rather, the use of control measures should be based upon a careful evaluation of conditions that do or can exist, and an economical solution reached that will accomplish the desired results.

Compaction characteristics

9. In column 9 of the table are shown the general compaction characteristics of the various soil groups. The evaluations given and the equipment listed are based on average field conditions where proper moisture control and thickness of lift are attained and a reasonable number of passes of the compaction equipment is required to secure the

desired density. For lift construction of embankments, the sheepsfoot roller and rubber-tired roller are commonly used pieces of equipment. Some advantages may be claimed for the sheepsfoot roller in that it leaves a rough surface that affords better bond between lifts, and it kneads the soil thus affording better moisture distribution. Rubber-tired equipment referred to in the table is considered to be heavily loaded compactors or earth-moving equipment with a minimum wheel load of 15,000 lb. If ordinary wobble-wheel rollers are used for compaction, the thickness of compacted lift is usually reduced to about 2 in. Granular soils with little or no fines generally show good compaction characteristics, with the well-graded materials, GW and SW, usually furnishing better results than the poorly-graded soils, GP and SP. The sandy soils in most cases are best compacted by crawler-type tractors; on the gravelly materials rubber-tired equipment and sometimes steel-wheel rollers are also effective. Coarse-grained soils with fines of low plasticity, groups GM and SM, show good compaction characteristics with either sheepsfoot rollers or rubber-tired equipment; however, the range of moisture contents for effective compaction may be very narrow, and close moisture control is desirable. This is also generally true of the silty soils in the ML group. Soils of the ML group may be compacted with rubber-tired equipment or with sheepsfoot rollers Gravels and sands with plastic fines, groups GC and SC, show fair compaction characteristics, although this quality may vary somewhat with the character and amount of fines; rubber-tired or sheepsfoot rollers may be used. Sheepsfoot rollers are generally used for compacting fine-grained soils. The compaction characteristics of such materials are variable -- lean clays and sandy clays

(CL) being the best, fat clays and lean organic clays or silts (OL and CH) fair to poor, and organic or micaceous soils (MH and OH) usually poor. For most construction projects of any magnitude it is highly desirable to investigate the compaction characteristics of the soil by means of a field test section. In column 10 of table A1 are shown ranges of unit dry weight of the soil groups for the standard AASHO (Proctor) compactive effort. It is emphasized that these values are for guidance only and design or construction control should be based on laboratory test results.

Suitability of soils for foundations

10. Suitability of soils for foundations of embankments or structures is primarily dependent on the strength and consolidation characteristics of the subsoils. Here again the type of structure and its use will largely govern the adaptability of a soil as a satisfactory foundation. For embankments, large settlements may be allowed and compensated for by overbuilding; whereas the allowable settlement of structures such as control towers, etc., may be small in order to prevent overstressing the concrete or steel of which they are built, or because of the necessity for adhering to established grades. Therefore a soil may be entirely satisfactory for one type of construction but may require special treatment for other types. Strength and settlement characteristics of soils are dependent upon a number of variables, such as structure, in-place density, moisture content, cycles of loading in their geologic history, etc., which are not readily evaluated by a classification system such as used here. For these reasons only very general statements can be made as to the suitability of the various soil types as foundations; this is especially true for fine-grained soils. In general, the gravels and

gravelly soils (GW, GP, GM, GC) have good bearing capacity and undergo little consolidation under load. Well-graded sands (SW) usually have a good bearing value. Poorly-graded sands and silty sands (SP, SM) may exhibit variable bearing capacity depending on their density; this is true to some extent for all the coarse-grained soils but is especially critical for uniformly graded soils of the SP and SM groups. Such soils when saturated may become "quick" and present an additional construction problem. Soils of the ML group may be subject to liquefaction and may have poor bearing capacity, particularly where heavy structure loads are involved. Of the fine-grained soils, the CL group is probably the best from a foundation standpoint, but in some cases the soils may be soft and wet and exhibit poor bearing capacity and fairly large settlements under load. Soils of the MH groups and normally-consolidated CH soils may show poor bearing capacity and large settlements. Organic soils, OL and OH, have poor bearing capacity and usually exhibit large settlement under load. For most of the fine-grained soils discussed above, the type of structure foundation selected is governed by such factors as the bearing capacity of the soil and the magnitude of the load. It is possible that simple spread footings might be adequate to carry the load without excessive settlement in many cases. If the soils are poor and structure loads are relatively heavy, then alternate methods are indicated. Pile foundations may be necessary in some cases and in special instances, particularly in the case of some CH and OH soils, it may be desirable and economically feasible to remove such soils from the foundation. Highly organic soils, Pt, generally are very poor foundation materials. These may be capable of carrying very light loads but in general are unsuited for most construction purposes. If highly organic soils occur in the foundation, they may be removed if limited in extent, they may be displaced by dumping firmer soils on top, or piling may be driven through them to a stronger layer, proper treatment will depend upon the structure involved.

Graphical Presentation of Soils Data

11. It is customary to present the results of soils explorations on drawings or plans as schematic representations of the borings or test pits with the soils encountered shown by various symbols. Commonly used hatching symbols are small irregular round symbols for gravel, dots for sand, vertical lines for silts, and diagonal lines for clays. Combinations of these symbols represent various combinations of materials found in the explorations. This system has been adapted to the various soil groups in the unified soil classification system and the appropriate symbols are shown in column 4 of table A1. As an alternative to the hatching symbols, they may be omitted and the appropriate group letter symbol (CL, etc.) written in the boring log. In addition to the symbols on logs of borings, the effective size, D_{10} (grain size in mm corresponding to 10 per cent finer by weight), of coarse-grained soils and the natural water content of fine-grained soils should be shown by the side of the log. Other descriptive abbreviations may be used as deemed appropriate. In certain special instances the use of color to delineate soil types on maps and drawings is desirable. A suggested color scheme to show the major soil groups is described in column 5 of table A1.

Table A1

CHARACTERISTICS PERTINENT TO EMBANKMENTS AND FOUNDATIONS

Major Divisions (1)	(2)	Letter (3)	Symbol: Hatching (4)	Symbol: Color (5)	Name (6)	Value for Embankments (7)	Permeability Cm Per Sec (8)	Compaction Characteristics (9)	Std AASHO Max Unit Dry Weight Lb Per Cu Ft (10)	Value for Foundations (11)	Requirements for Seepage Control (12)
COARSE GRAINED SOILS	GRAVEL AND GRAVELLY SOILS	GW		Red	Well graded gravels or gravel sand mixtures, little or no fines	Very stable, pervious shells of dikes and dams	$k > 10^{2}$	Good, tractor, rubber-tired, steel-wheeled roller	125 135	Good bearing value	Positive cutoff
		GP		Red	Poorly-graded gravels or gravel sand mixtures, little or no fines	Reasonably stable, pervious shells of dikes and dams	$k > 10^{2}$	Good, tractor, rubber-tired, steel wheeled roller	115 125	Good bearing value	Positive cutoff
		GM		Yellow	Silty gravels, gravel sand silt mixtures	Reasonably stable, not particularly suited to shells, but may be used for impervious cores or blankets	$k = 10^{3}$ to 10^{6}	Good, with close control, rubber-tired, sheepsfoot roller	120 135	Good bearing value	Toe trench to none
		GC		Yellow	Clayey gravels, gravel sand clay mixtures	Fairly stable, may be used for impervious core	$k = 10^{6}$ to 10^{8}	Fair, rubber tired, sheepsfoot roller	115 130	Good bearing value	None
	SAND AND SANDY SOILS	SW		Red	Well graded sands or gravelly sands, little or no fines	Very stable, pervious sections, slope protection required	$k > 10^{3}$	Good, tractor	110 130	Good bearing value	Upstream blanket and toe drainage or wells
		SP		Red	Poorly-graded sands or gravelly sands, little or no fines	Reasonably stable, may be used in dike section with flat slopes	$k > 10^{3}$	Good, tractor	100 120	Good to poor bearing value depending on density	Upstream blanket and toe drainage or wells
		SM		Yellow	Silty sands, sand silt mixtures	Fairly stable, not particularly suited to shells, but may be used for impervious cores or dikes	$k = 10^{3}$ to 10^{6}	Good, with close control, rubber tired, sheepsfoot roller	110 125	Good to poor bearing value depending on density	Upstream blanket and toe drainage or wells
		SC		Yellow	Clayey sands, sand silt mixtures	Fairly stable, use for impervious core for flood control structures	$k = 10^{6}$ to 10^{8}	Fair, sheepsfoot roller, rubber tired	105 125	Good to poor bearing value	None
FINE GRAINED SOILS	SILTS AND CLAYS LL < 50	ML		Green	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity	Poor stability, may be used for embankments with proper control	$k = 10^{3}$ to 10^{6}	Good to poor, close control essential, rubber-tired roller, sheepsfoot roller	95 120	Very poor, susceptible to liquefaction	Toe trench to none
		CL		Green	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays	Stable, impervious cores and blankets	$k = 10^{6}$ to 10^{8}	Fair to good, sheepsfoot roller, rubber tired	95 120	Good to poor bearing	None
		OL		Green	Organic silts and organic silt clays of low plasticity	Not suitable for embankments	$k = 10^{4}$ to 10^{6}	Fair to poor, sheepsfoot roller	80 100	Fair to poor bearing may have excessive settlements	None
	SILTS AND CLAYS LL > 50	MH		Blue	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts	Poor stability, core of hydraulic fill dam, not desirable in rolled fill construction	$k = 10^{4}$ to 10^{6}	Poor to very poor, sheepsfoot roller	70 95	Poor bearing	None
		CH		Blue	Inorganic clays of high plasticity, fat clays	Fair stability with flat slopes, thin cores, blankets and dike sections	$k = 10^{6}$ to 10^{8}	Fair to poor, sheepsfoot roller	75 105	Fair to poor bearing	None
		OH		Blue	Organic clays of medium to high plasticity, organic silts	Not suitable for embankments	$k = 10^{6}$ to 10^{8}	Poor to very poor, sheepsfoot roller	65 100	Very poor bearing	None
HIGHLY ORGANIC SOILS		Pt		Orange	Peat and other highly organic soils	Not used for construction		Compaction not practical		Remove from foundations	

Notes:
1. Values in columns 7 and 11 are for guidance only. Design should be based on test results.
2. In column 9, the equipment listed will usually produce the desired densities with a reasonable number of passes when moisture conditions and thickness of lift are properly controlled.
3. Column 10 unit dry weights are for compacted soil at optimum moisture content for Standard AASHO (Standard Proctor) compactive effort.

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